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TRANSACTIONS.

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(Communicated by Mr John Murray.)

During the cruise of H.M.S. "Triton" a small but very interesting collection of Pycnogonids was made. Mr John Murray sent it over to me, and asked me to prepare a report on it, which I gladly undertook to do.

The thirteen stations of the "Triton" cruise are situated about 60° lat. north, and between 6° and 9° 6′ long. west of Greenwich. At six of these stations Pycnogonids were obtained. The depth of the sea at these stations varies from 433 to 640 fathoms; at two of them the bottom was hard ground or stones, at three the bottom was mud, at one ooze. At three of the stations the bottom temperature was about 45°, at the three others about 30°. The first three being in the so-called warm area, the latter in the cold area.

The number of species collected amounts to eleven. Three of them inhabit the cold area, and were not found in the warm area (*Nymphon Strömii*, Kröyer; *Colossendeis proboscidea*, Sab. spec.; and *C. angusta*, G. O. Sars); five species were observed only in the warm area (*Nymphon hirtipes*, Bell; *N. macrum*, Wilson; *N. longitarse*, Kröyer; *Pallene malleolata*, G. O. Sars; *Pallenopsis tritonis*, n. sp.). The remaining three seem to inhabit the cold as well as the warm area. *Nymphon macronyx*, G. O. Sars, however, is represented by several hundred specimens from the cold area, and by one specimen only from the warm area; and this is also the case with *Nymphon robustum*, Bell. Of both species the number of specimens collected at stations in the cold area was so large, that the occurrence of one specimen at a station in the warm area seems rather unimportant—it must be considered as a specimen which has got astray; but whether this happened before or after its being dredged, I cannot say with certainty. As in both instances the station in the warm area from which the single specimen was obtained follows one in the cold area,

at which several hundred specimens of the one, and upwards of fifty of the other, species were collected, it is even probable that—the same fishing apparatus (trawl) being used—one specimen was overlooked either remaining between the meshes of the trawl or clinging to the rope. The nature of the animals, with their long and numerous legs, each furnished with a claw, favours this suggestion. The only specimen which remains as inhabiting both areas is *Nymphon grossipes*, Oth. Fabr.: it is represented by eight specimens, four of which are from the cold water area, and four from the warm water area.

Comparing these facts with those furnished by the cruise of the "Knight Errant" (1880), of the "Vöringen" (1876 and 77–78), and of the "Willem Barents" (1878 and 1879), and also with what is known about the Pycnogonids of the North American coast (for which knowledge we are much indebted to the studies of Mr E. B. Wilson), we have made the following table, from which those species are excluded which have hitherto been only once observed :—

Name of the Species.	Area in which H. M. S. 'Triton' caught it.	Area in which the 'KnightErrant' caught it.	Area in which G. O. Sars caught it.	Does it inhabit the Arctic Sea ?	Does it inhabit the Atlantic near the N. American coast ?
Nymphon robustum, Bell, . .	Cold	Cold	Cold	Yes	No
„ *macronyx*, G. G. Sars, .	Cold	Cold	Cold	?	No
„ *Strömii*, Kröyer, . .	Cold	Both	Cold	Yes	Yes
„ *hirtipes*, Bell, . .	Warm	...	Cold	Yes	Yes
„ *macrum*, Wilson, . .	Warm	...	...	No	Yes
„ *longitarse*, Kröyer, .	Warm	...	Warm	Yes	Yes
„ *grossipes*, Oth. Fabr., .	Both	Cold	Cold	Yes	Yes
„ *serratum*, G. O. Sars, .	...	...	Both	Yes	No
Colossendeis proboscidea, Sab. spec.,	Cold	Cold	Cold	Yes	No
„ *angusta*, G. O. Sars, .	Cold	...	Cold	?	Yes
Pallene malleolata, G. O. Sars, .	Warm	...	Both	?	No
Pallenopsis tritonis, n. sp., . .	Warm	...	...	No	Probably

From this table the following conclusions may be deduced :—

1. The species which inhabit the cold area in the Atlantic occur also in the Arctic Ocean (*N. robustum*, *C. proboscidea*); those which have not yet been observed in the Arctic may be expected to be found there (*N. macronyx*, *C. angusta*). They are not found near the American coast, or only at a very considerable depth (*Colossendeis angusta* at a depth from 810 to 1242 fathoms).

2. The species which inhabit the warm area in the Atlantic occur also at a much lower latitude near the American coast (*N. macrum, Pallenopsis,* spec.). They are not found in the Arctic Ocean.

3. The species which inhabit both areas in the Atlantic occur in the Arctic Ocean as well as near the American coast (*N. Strömii, N. hirtipes, N. grossipes*). *Nymphon serratum* inhabits both areas in the Atlantic; it has been observed in the Arctic, and will probably be found at a much lower latitude. *Pallene malleolata* inhabits both areas also, and will probably be found to have a wide northern as well as southern distribution.

4. The only species whose distribution does not seem to be in accordance with the temperature of the water it inhabits is *N. longitarse.* Hitherto it has only been observed in the warm water area, yet it inhabits the Arctic as well as the New England coast. However, I think this exception is of no consequence: in the first place, because it always, in the northern parts of the Atlantic at least, lives rather solitary, and therefore may be found in the future in the cold area also; and in the second place, because it is a somewhat uncertain species, and perhaps will turn out to be a variety of *N. grossipes.*

A few notes on the species submitted to my examination are appended here:—

1. *Nymphon robustum,* Bell.

A very large number of specimens of this species was obtained at Stations 8 and 9, fourteen specimens were dredged at Station 6, and one specimen was taken from the bottle which contained the Pycnogonids of Station No. 10. The specimens show the same difference with those of higher northern latitudes as do those dredged by the "Knight Errant" in 1880; they are not nearly so stout, and are smaller. Numerous specimens had attached to the legs a *Scalpellum,* for which I proposed the name *Scalpellum nymphocola.* It is a curious fact, that the specimens of the Barents Sea (and I studied also those of the third and fourth cruise of the Dutch schooner "Willem Barents") never had this Cirriped on their legs.

2. *Nymphon hirtipes,* Bell.

Only one small specimen of this species was dredged at Station No. 5. Mr Edmund B. Wilson and Professor G. O. Sars apply to this species the name *N. hirtum,* Fabr. But the description of Fabricius (*Entom. System.,* 1794) is not only very brief, but it is totally insufficient to recognise the species. The species which Kröyer (1845) described under the name *N. hirtum,* Fabr., no doubt differs from the present species (as is stated by Professor Sars and by

WILSON also). I therefore retain the name of FABRICIUS for KRÖYER's species, the first that has been described recognisable under that name, and I give to the other the name of BELL, whose figures and description doubtless refer to it.

Although this species is common in high northern latitudes (BELL, MIERS, HOEK), it seems to be rather scarce in the North Atlantic (Professor G. O. SARS only observed it once; it was not obtained by the "Knight Errant"; and the "Triton" collected only one specimen). Off Halifax it was taken in great numbers by the U.S. Fish Commission in 1877 (Wilson).

3. *Nymphon Strömii*, Kröyer.

During the cruise of H.M.S. "Triton" this species was met with on three different occasions. At Station 9 about forty specimens of it were taken; at Station 8, three, and at Station 6, one specimen. It was not observed at one of the stations of the warm area, as happened during the cruise of the "Knight Errant."

4. *Nymphon macronyx*, G. O. Sars.

This species was first observed by Professor SARS during the first cruise of the "Vöringen" (1876); it was again collected in the Faroe Channel during the summer of 1880 ("Knight Errant"); and it is now dredged for the third time by H.M.S. "Triton." Professor SARS collected four specimens; the "Knight Errant" took about thirty specimens; and the "Triton" several hundreds. These specimens were obtained in about lat. 60° north, whereas SARS got his specimens at 62° 44′ 5″. Whether its distribution will be found to extend still further north, I cannot say with certainty. I only think it very probable, as this species is an inhabitant of the cold area.

At Station 8, several hundred specimens of this species were taken,
" 9, about fifty specimens " "
" 6, " two " " "

and one specimen (see p. 1) was found in the bottle containing the Pycnogonids from Station 10.

One of the specimens of Station 8 has no eyes; or, better perhaps, has no pigment in its eyes.

5. *Nymphon macrum*, Wilson.

WILSON, Pycnogonida of New England, *Report U.S. Commission of Fish and Fisheries*, vi. (1878), 1881, p. 487, pl. iv., figs. 21–23.
Syn. *Nymphon brevicollum*, Hoek, Report "Challenger" Pycnogonida, 1881, p. 45, pl. iii. figs. 13–15; pls. xv. figs. 12 and 13.

The general appearance of this species is much like *N. Strömii*. When studying the details as to the length of the joints of the palpi, of the tarsal joints

of the legs, the structure of the first segment of the body, of the oculiferous tubercle, &c., it is, however, easily distinguished not only from the above named, but also from other species of the genus.

The eggs of *N. Strömii* are small and very numerous; those of *N. macrum* are very large, each egg-mass containing a few eggs only.

This species inhabits the warm water area. Four specimens were collected at Station 10; nineteen specimens at Station 11.

The U.S. Fish Commission took this species at a few localities in the Gulf of Maine, in from 85 to 115 fathoms; the "Challenger" south of Halifax, in 83 fathoms. The depth at which it was collected during the cruise of H.M.S. "Triton" was between 516 and 555 fathoms.

6. *Nymphon grossipes*, Oth. Fabr.

In all, eight specimens which I refer to this species were collected. In most of its characters this species is very variable; its conical and acutely pointed oculiferous tubercle, the length of the third joint of the palpus, which is longer than the second joint, and the armature of the second tarsal joint of the leg, are, I think, the best marks for its distinction.

Hitherto, this species was, in the Northern Atlantic, only observed in the cold area. H.M.S. "Triton" collected four specimens in the warm and four in the cold area, viz., three at Station 6, one at Station 9, and four at Station 10.

7. *Nymphon longitarse*, Kröyer.

At Station 11, at a depth of 555 fathoms, two specimens of this species were dredged. They are very small specimens, having an extremely attenuated appearance, with blunt oculiferous tubercles, and with the first tarsal joint twice as long as the second.

8. *Colossendeis proboscidea*, Sab. spec.

This robust species is represented by a single specimen taken at Station 9, at a depth of 608 fathoms. For a figure of this species I refer to my paper on the Pycnogonids of the "Willem Barents."

9. *Colossendeis angusta*, G. O. Sars.

G. O. Sars, Prodromus descriptionis, *Arch. for Math. og Naturv.*, ii. p. 268, 1877.

(Plate I. fig. 8.)

This species is known from a short (Latin) description by Professor G. O. Sars. Mr Wilson (*Bull. Mus. Comp. Zool.*, viii. 1881, p. 243) got specimens of what he believes to be the same species from deep water in the Atlantic, between N. lat. 38° and 41°, and W. long. 65° and 73°, and points out several differences of greater or less importance between his specimens and those of Sars.

Some of these differences may be due to variation of the species, the others to the provisional character of the paper of Professor SARS. Nor would I have insisted upon this disagreement had not the specimens collected with H.M.S. "Triton" shown also some of the variations from the description of SARS pointed out by WILSON.

The largest specimen collected by the "Triton" measures 20 mm.; the proboscis, which is slightly swollen a little behind the middle, is not quite 10 mm. The abdomen, according to SARS and WILSON, is one-third the length of the trunk; in the "Triton" specimens, however, it is only one-fourth that length. The third (second, SARS) joint of the palpus is a great deal longer than the fifth (fourth, SARS). The eighth joint of the palpus is globose, and much shorter than the two last. The claw of the ovigerous leg is not confluent with the last joint (SARS): in my specimens, as in those of WILSON, there is a distinct articulation between them. The colour of the specimens is beautiful orange.

There are in all eight specimens. Of these five are from 16 to 20 mm., and about, or quite, full grown. The three other specimens measure from 9 to 12 mm., and are furnished with very slender and three-jointed mandibles (fig. 8). The last joint of these mandibles terminate in minute rudimentary chelæ.

I observed the same in a young male specimen of *Colossendeis gracilis* collected during the cruise of H.M.S. "Challenger" (*vide* Report "Challenger" *Pycnogonida*, p. 69). It is a very curious fact that some of the species of the genus *Colossendeis* retain a pair of appendices of the larval state almost till the animal has reached the size of the adult; and these appendices do not remain in the extremely small and feeble condition of larval life, but grow with the proboscis till the length of this part of the body surpasses half its length when full grown. Probably the mandibles are only lost when the animal comes to maturity.

This species is an inhabitant of the cold water area; the highest latitude at which it has been observed is 63° 10′ 2″: it has not been found as yet in the Arctic region. SARS obtained it from 417, the "Triton" from 466 to 640 fathoms. Off the eastern coast of the United States Mr AGASSIZ has dredged it at a depth of from 810 to 1242 fathoms—a striking instance of the southward extension of Arctic forms in deep water, as Mr WILSON says; for though it has not been found in the Arctic Ocean as yet, we may safely conclude, from its occurrence in the cold water area, that hereafter it will be met with there.

Seven specimens were taken at Station No. 8 and one at Station No. 6.

10. *Pallene malleolata*, G. O. Sars.

G. O. SARS, Crustacea et Pycnogonida nova, *Arch. for Math. og Naturv.*, iv. p. 469, 1879.

(Plate I. fig. 7.)

I know this species only from the description of Professor G. O. SARS.

Four robust specimens were taken at Station No. 10 at a depth of 516 fathoms. It is the only representative of the genus found at a considerable depth in high northern latitudes. Professor SARS collected it between N. lat. 72° 27′ and 80°; the station at which the "Triton" dredged it is N. lat. 59° 39′ 30″, in the warm area.

11. *Pallenopsis tritonis*, n. sp.

(Plate I. figs. 1–6.)

Animal slender, the lateral processes, at the end of which the legs are inserted, being distinctly separated from each other. Dark yellow coloured, smooth: no tubercles or hairs are visible on the surface of the body even when studied with a lens. Legs not very hairy; the structure of the hairs, as in numerous species of *Pallene* and *Pallenopsis*, furnished with small barbs pointing towards the tip.

Proboscis nearly cylindrical, slightly swollen a little behind the middle. Mouth large, as in the other species of the genus (*Pallenopsis oscitans*, Hoek, spec. &c.). The length of the proboscis is not quite equal to that of the oculiferous and two succeeding segments taken together.

Oculiferous segment longer than the two following taken together, somewhat swollen in front, where it overhangs the base of the proboscis, and where it is furnished with the rounded oculiferous tubercle. Of the eyes the two anterior ones have very large clear lenses; the other two are a great deal smaller and are placed at the back side of the tubercle, a dark reddish and rhombiform pigment spot being placed at the tip of the tubercle.

The form of the other segments is the same as in other species of the genus; the abdomen is cylindrical, its length corresponds with that of the second and third segments taken together (fig. 1).

The mandibles are very slender, the two basal joints extend beyond the tip of the rostrum, third joint considerably swollen, with the claws curved and not so long as in *P. longirostris*, Wilson (fig. 2).

The palpi are represented by very small globular knobs implanted laterally near the base of the proboscis.

The ovigerous legs (figs. 3 and 4) have the first joint almost globular, the second, fourth, and fifth joints of considerable and nearly equal length, the third a great deal longer than the first, and also a little longer than the sixth joint, which is swollen at the distal extremity. Seventh to tenth joints gradually diminishing in length, and at the same time growing more slender. Tenth joint rather elongate. Joints first to fifth are sparsely hairy, joints sixth to tenth covered with numerous spines; those at the distal extremity of the sixth joint are a great deal stouter, and are placed in a complete ring.

The legs are exactly thrice as long as the body (with the proboscis enclosed);

the length of the different joints is as follows:—First and third joint as long as the lateral process, at the end of which the leg is inserted. Second joint more than thrice as long as the first, slightly swollen towards its distal extremity. Fourth joint more than twice as long as the second, and even a little longer than the fifth joint. Sixth, seventh, and eighth joints combined once and a half as long as the fifth. First to fourth joint almost of the same thickness, fifth to eighth joint gradually growing more slender; all the joints are furnished with a longitudinal darker coloured stripe, as is common in Pycnogonids. The first three joints of the legs are almost quite smooth, the outer joints rather hairy. The structure of the last two joints of the leg can be judged from fig. 5. They are not so slender as the same joints of *P. longirostris* as figured by Wilson. The armature, however, is much the same as in that species.

The only specimen of this species which was collected by the "Triton" is a male; as far as I could make out without mutilating the animal, the small genital pores are only present on the two hindermost legs, and situated ventrally near the distal extremity of the second joint. The ovigerous leg contains a glandular organ with small opening near the beginning of the fourth joint, and so does the fourth joint of all the legs. Of the latter the porus is placed at the end of a tubular process* inserted about the middle of the joint. As shown in fig. 6, the excretory canal, which passes through the tubular process, has a vesicular swelling at its base. Most probably these glandular organs do not occur in the females of this species.

The intestinal cæcum which enters the mandible in this species is well developed (fig. 2); it can be traced till in the last, the claws bearing joint. The total length of the body is $8\frac{5}{7}$ mm., that of a leg of the hindermost pair 26 mm.

Together with *Pallene malleolata*, *Nymphon macronyx*, and *N. macrum*, this interesting Pycnogonid was dredged at Station 10 of the cruise of H.M.S. "Triton." A young Lamellibranch mollusc (an oyster ?) is affixed to one of its legs.

Mr E. B. Wilson (1881) proposed a new genus for those Pycnogonids which come near to *Phoxichilidium*, M. Edw., but which are characterised by three-jointed (four-jointed, Wilson) mandibles and ten-jointed ovigerous legs present in both sexes. Moreover, it is distinct on account of the existence of rudimentary palpi. Wilson describes two species as belonging to this genus, *P. forficifer* and *P. longirostris*, and he supposes that Kröyer's *Phoxichilidium fluminense* should also be referred to this genus. No doubt he is right in this supposition, although the extra articulation of the mandible is wanting

* Wilson hints that this glandular duct might be a character of generic significance. It occurs, however, in numerous genera, as in *Phoxichilidium*, *Oorhynchus*, &c.

in this species. If the genus *Pallenopsis* be accepted, four other species of deep-sea Pycnogonids, collected during the voyage of H.M.S. "Challenger," and described in my report on the Pycnogonids as belonging to *Phoxichilidium*, Milne Edw., belong doubtless to it also. So we have eight species of this genus, the range of depth and geographical distribution of which may be judged from the following list :—

Name of the Species.	Depth in Fathoms.	Geographical Distribution.
Pallenopsis fluminensis, Kröyer, spec.,	7–20	Patagonia, Brazil.
„ *patagonica*, Hoek, spec.,	45–175	Patagonia.
„ *forficifer*, Wilson,	262-333	Off South Carolina.
„ *longirostris*, Wilson,	500	South of Cape Cod.
„ *tritonis*, n. sp.,	516	Faroe Channel.
„ *pilosa*, Hoek, spec.,	1600–1950	Southern Indian Ocean.
„ *oscitans*, Hoek, spec.,	1675	Atlantic, West of Azores.
„ *mollissima*, Hoek, spec.,	1875	Off Yeddo (Japan).

Of these, six are true deep-sea species, the two others are shallow-water inhabitants. The deep-sea species have the mandibles three-jointed (as are those of the young of *Colossendeis* and *Ascorhynchus*); the two shallow-water species show a transitory form between those with three and those with two-jointed mandibles. In the mandible of *P. patagonica* a trace of an articulation is visible dorsally, but totally wanting when seen from the ventral side; in *P. fluminensis*, a little beyond the middle, the basal joint of the mandibles is furnished with a row of hairs, and seems to be divided into two.

Within the limits of the genus *Pallenopsis* the change of three-jointed into two-jointed mandibles has taken place. That the three-jointed mandible must be considered as the original form is shown by the mandibles of different species of *Ascorhynchus* and *Colossendeis;* though they exist in these genera as rudimentary or larval organs only and are too small and too weak to be of use to the animal, they are distinctly three-jointed. Larval parts, or parts which have grown rudimentary, are no more strongly influenced by circumstances; hence they often retain their original condition. No doubt it is a very curious coincidence, that the deep-sea species show the original condition of the mandibles, whereas the shallow-water forms are furnished with these organs in the more robust condition of most of the other genera of Pycnogonids.

Finally, I wish to point out that the new species for which I have proposed the name *P. tritonis* comes very near to *P. longirostris*, Wilson. I was long uncertain whether I should refer my specimen to that species or should describe it as a new one. I chose the latter, because of numerous, though perhaps not very important, differences between his description and my specimen. Should

the two forms prove identical—as I think it very probable they will do when examined comparatively—they give new evidence of the wide range of deep-sea species.

LIST OF THE STATIONS at which Pycnogonids were taken by H.M.S. "Triton."

Station No. 5, August 9, 1882.—Lat. 60° 11′ 45″ N., long. 8° 15′ W.; 433 fathoms. Bottom, hard ground; temp. 43°, 5 (Trawl).

Station No. 6, August 17, 1882.—Lat. 60° 9′ N., long. 7° 16′ 30″ W.; 466 fathoms. Bottom, stones; temp. 30°–29°, 5 (Dredge).

Station No. 8, August 22, 1882.—Lat. 60° 18′ N., long. 6° 15′ W.; 640 fathoms. Bottom, mud; temp. 30° (Trawl).

Station No. 9, August 23, 1882.—Lat. 60° 5′ N.; long. 6° 21′ W.; 608 fathoms. Bottom, mud; temp. 30° (Trawl).

Station No. 10, August 24, 1882.—Lat. 59° 40′ N., long. 7° 21′ W.; 516 fathoms. Bottom, mud; temp. 46°–49°, 5 (Trawl).

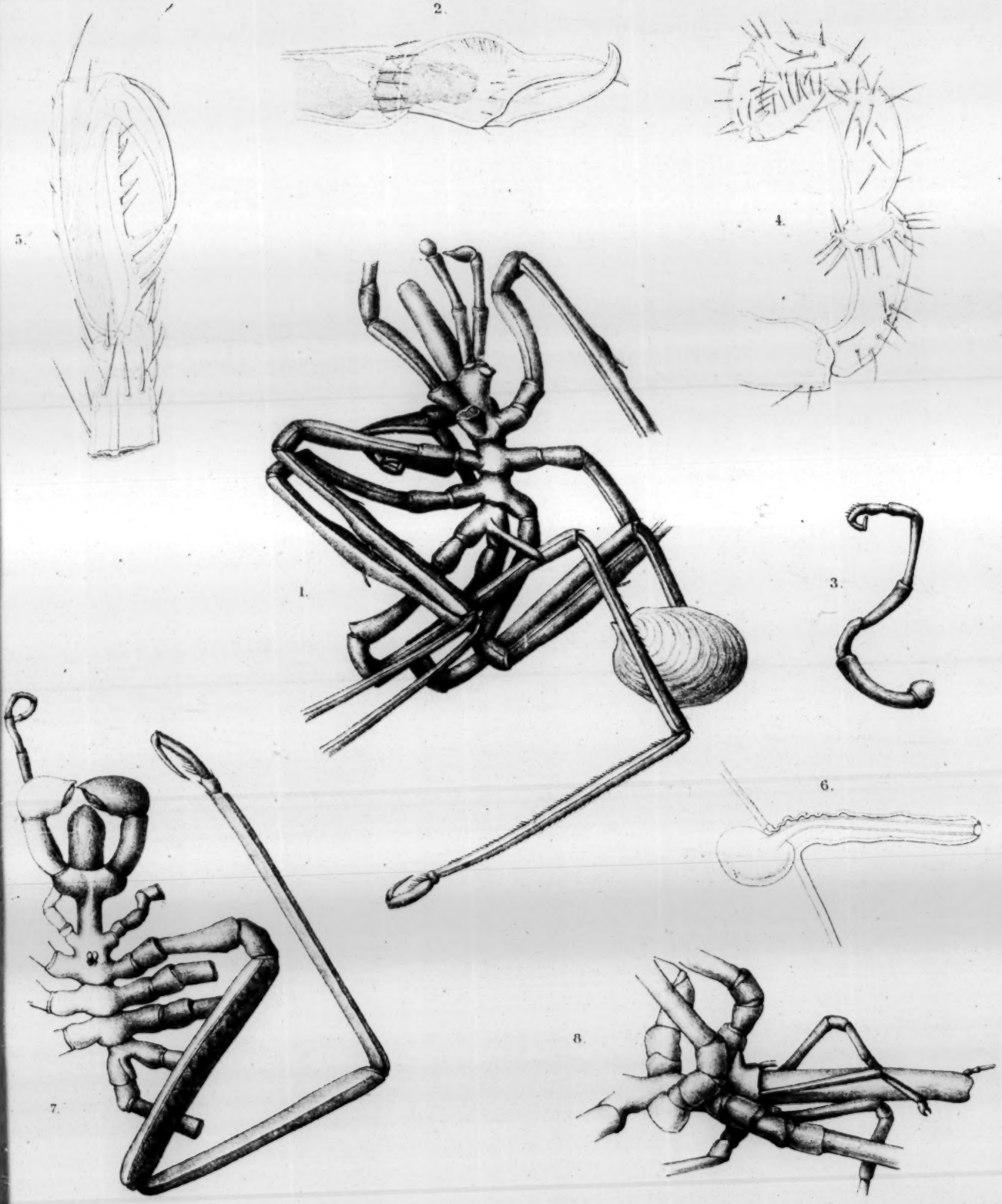
Station No. 11, August 28, 1882.—Lat. 59° 39′ 30″ N., long. 7° 13′ W.; 555 fathoms. Bottom, ooze; temp. 45°, 5 (Trawl and Dredge).

EXPLANATION OF PLATE I.

Figs. 1–6, illustrating *Pallenopsis tritonis*, n. sp.

Fig. 1. Animal, dorsal view; magnified 7 diameters.
Fig. 2. Last joint of the mandible; magnified 41 diameters.
Fig. 3. Ovigerous leg; magnified 7 diameters.
Fig. 4. Last five joints of the ovigerous leg; magnified 41 diameters.
Fig. 5. Last two joints and claw of one of the legs; magnified 41 diameters.
Fig. 6. Tubular process of one of the legs; magnified 94 diameters.
Fig. 7. *Pallene malleolata*, G. O. Sars, dorsal view; magnified 6 diameters.
Fig. 8. *Colossendeis angusta*, G. O. Sars, lateral view of the anterior part of the body; magnified 7 diameters.

(All the figures are drawn with the camera lucida.)



A.J Wendel, lith.

PYCNOGONIDA OF THE CRUISE OF H. M. S. TRITON.

II.—*Bright Clouds on a Dark Night Sky.* By C. Piazzi Smyth, Astronomer-Royal for Scotland. (Plates II. to XIV.)

(Read 18th June 1883.)

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Part I.

On a moonless night, whenever clouds of an ordinary elevation in the atmosphere appear upon, or pass across, the star-spangled sky behind them, they exhibit themselves, as a rule, dark, sometimes even black, in comparison therewith. And no wonder, when every part of the open sky from visible star to visible star therein must be lit up to some, though doubtless a very small, extent by the faintest general and cumulative radiance of those myriads and myriads of lesser stars, which only a large telescope can show to be individually existent as actual stellar points of light, but in their aggregate more nearly eternal, and still more constant from age to age, than our gigantic Sun itself.

If the heavens become entirely covered by such clouds, a very dark night is the usual and natural result. That at least is my experience on the Calton Hill through thirty years of observation; and something very like it is probably so generally recognised as fact over the whole country, that this formal statement about it, may appear to many persons a needless truism.

Yet such darkness of elevated midnight clouds is not without exception. For on April 8, 1882, on looking out Northward about 9.30 P.M. from an upper chamber in the house No. 15 Royal Terrace, to see if there was any Aurora to observe, I saw indeed no Aurora, but in place of it two or three decidedly luminous clouds, on an otherwise dark by comparison, but star-bearing, sky.

The rounded forms of these clouds were so contrary to the regular arcs and needle-shaped darts of Aurora, and there was so marked an absence of the very dark regions which usually appear on the Northern horizon, low down underneath an Auroral display, that I went next to the South side of the house, and there, to my greater surprise, saw that all the clouds visible from thence were luminous with a white, moon-like radiance. Any portions of sky between

them appeared by contrast of pitch-like darkness, though without preventing a good sized star from shining forth;—and the brightness of the clouds continually increased from the Zenith down towards the Southern direction, so far as the neighbouring Calton Hill allowed one to look into that quarter.

The affair was so unusual, that I immediately made my preparation for going expressly to the top of the said Calton Hill, in order to look further down South, and see what strange source of light there could be there, illuminating the clouds so strongly;—for the Almanac declared that there was no Moon in the position at that time, nor would be for several hours.

The ascent of the hill under such circumstances was rather tantalising;—for the first part of the way, by bringing one closer thereto, produces a higher angle of obstruction for the summit,—and meanwhile the clouds overhead and around, glowed with such an unnatural glare of light, as made me fear it could not last long, and that I might be too late after all to see its origin in full force, and behold whence it came. Tree tops of neighbouring gardens projected on some of these clouds, showed their detail of twigs with almost daylight minuteness; and on coming into view of Nelson's Monument, though still a long way off, there was not only the Time-Ball on its summit, but there were its staff and cross-arms, each and every one clearly visible and even black and sharp against one of these preter-naturally bright clouds. But on reaching the top of the hill, and getting a view from thence right down to the Southern horizon, there was nothing there in the heavens, or apparently anywhere else to account for the strange scene up above. The effect so very strong up there, simply died away from inanition in the distance towards the South.

Baffled then and disappointed I entered the Royal Observatory enclosure and watched the strange bright clouds overhead or nearly so, as they were wafted about, but chiefly from East to West, for nearly a couple of hours. The air was cold and dry. The clouds were of the massive, but irregular figure of cumuli when seen at a high angle of altitude, and their light gave to spectroscopic examination nothing but the faintest continuous spectrum in the green region. Not in the slightest degree therefore like Aurora, with its sharp citron line; but rather like the faintest trace of carbon-flame illumination.

Gradually the disastrous and humbling idea grew in my mind,—that this wondrous phenomenon of luminous night clouds was nothing but their reflection of the gas-lights of Edinburgh and Leith, Portobello and Granton; and I tried to dismiss the matter from my mind. But every subsequent night that showed the usual rule of clouds dark against a starry sky,—though said clouds were illuminated by just the same city gas-lights,—brought up the further and perhaps more important question "why and how were clouds able to reflect such abundant light on that one night of April 8 alone?"

Besides the postulate that the air must have been very clear, two other

possible reasons suggested themselves. One was, that the clouds were low, and therefore nearer the lights that illuminated them. The other, that they affected on that night some peculiar physical structure which enabled them to reflect with far more than their wonted degree of brilliance.

The first of these two reasons, however, did not seem very important; for though *cumulus* clouds are never very high in the atmosphere, say about 3000 feet, rain-clouds are often lower and show no such light; indeed they are usually the blackest of night-clouds. This very circumstance therefore led to expecting that the bright appearance of April 8, might be due to just the opposite condition of the atmosphere, which moreover did then to some extent prevail, in the shape of dry, Scottish spring weather and its undesirable "clouds without water." That is without any to fall as rain, though there must have been some retained to form the visible mass of the cloud and reflect light with extra force.

Such an idea may bring into play our reason No. 2; but before launching on that hypothesis, it will be well to ascertain whether there was anything extraordinary in the dryness, or indeed in any of the other meteorological conditions of that one night, contrasting strongly with those of the nights immediately before and after.

To this end I have been kindly permitted by the Secretary of the Scottish Meteorological Society to make use of the Schedules of that hard-working body. And after having selected 24 of them on account of either their topographical neighbourhood or high character, I have extracted their bi-diurnal observations from April 6 to April 10, or for two days before, as well as two days after, the phenomenal night of April 8, as will be seen in Appendix I., and have graphically represented their Hygrometry in Appendix II.

One and one only of the 24 observers says there was Aurora that night; and I have requested the Secretary to communicate with him, and ascertain exactly what he saw and how he knew it to be Aurora.* But otherwise there was nothing remarkable in any of the returns except the Hygrometric. The Barometer was high, about 30·3 inches; the Thermometer low, about 41°·0; the mean Depression of the Wet-bulb about 2°·5, and the Wind generally from the East.

Now so far as Barometer, Thermometer, and wind are concerned the observers were, probably all of them, perfectly competent. But in the more delicate and sensitive matter of the Depression of the Wet-bulb by evaporation, —I have found it needful to reject three of them for reasons wherein I trust to be supported. Thus in a certain case which I will only allude to as No. 14, and wherein that usually most varying quantity (Depression of Wet-bulb), is made to read exactly 1° degree both morning and evening and day after day through

* See Appendix IV.

almost the whole period,—there was too evidently something, somewhere wanting in that observer.

Again in No. 9 the differences from morning to evening are better expressed, but the wet-bulb is too often higher than the dry-bulb, to be fully credible. And in No. 11, the observer, by simply entering the depression as always 1 degree, unless when he sometimes makes it just 2 degrees, shows that he is not aware of either the refinement, the truth, or the power of this beautiful method of arriving scientifically at the Hygrometric state of the air about him.

But of the remaining 21 stations, a notable majority does show a very remarkable depression of the wet-bulb to have occurred on the 8th of April, 1882; and without anything similar to it on the other days, either before or after.

Thus North Esk Reservoir, height 1150 feet, had a wet-bulb depression that night of 5°·8, in place of a 3° average.

Wanlockhead, 1334 feet high, had a depression of 6°·8 in place of its average 3°·5.

Moffat, 350 feet high, had 6°·9, in place of 2°·5.

Greenock, 233 feet high, had 12°·2, in place of 4°·5.

Paisley, 88 feet high, had 5°·0, in place of 3°·5. And

Glasgow, 54 feet high, had 5°·0, in place of 2°·5.

While at other stations, the anomaly occurred earlier in the day, or at the 9 A.M., in place of the 9 P.M. observation: thus—

Braemar, 1114 feet high, had 4°·5, in place of an average 3°·0.

New Pitsligo, 495 feet high, had 2°·6, in place of 1°·2.

Stobo Castle, 600 feet high, had 7°·0, in place of 3°·0.

Stronvar, 428 feet high, had 4°·0, in place of 2°·2.

Dalkeith, 190 feet high, had 3°·5, in place of 2°·3.

Callton Mor, 135 feet high, had 13°·0, in place of 4°·0.

Balloch Castle, 93 feet high, had 5°·3, in place of 2°·2.

Eallabus, 71 feet high, had 8°·0, in place of 4°·0.

Aberdeen, 66 feet high, had 2°·9, in place of 2°·3. And

Gordon Castle, 104 feet high, had 7°·9, in place of 3°·8.

Taken only so far, though very confirmatory on the whole, there are larger anomalies among the stations, both as to quantity and time, than is desirable. I therefore applied next to Mr W. H. M. CHRISTIE, Astronomer-Royal, at Greenwich, for the hourly observations of the self-recording dry and wet bulb thermometers there; and made the same request to Mr ROBERT H. SCOTT, for the returns from the Meteorological Council's Observatories of Glasgow and Aberdeen. They kindly responded, and their communicated observations are contained in Appendix III.

But before using them in the whole, I extracted their 9 A.M. and 9 P.M. observations, and projected them in the same manner as had been done with the 24 Scottish Stations; when there came out a most puzzling result;—viz.

At Glasgow, in place of the expected evening depression, there was positively an elevation. And

At Aberdeen, in place of the small morning depression of 2°·9, there was the immense one of 6°·7; the average one being only 2°·3.

On using, in place of the single observations of 9 A.M. and 9 P.M., the means of the whole 12 hours of observations A.M. and P.M.,—the anomalies of the curves were largely removed. And at length on projecting every observation, and obtaining a nearly continuous history of the wet-bulb depression through the whole 24 hours of each of the 5 days—the anomalies were all most abundantly and exquisitely explained.

An enormous depression, it was thus ascertained, had really occurred at Glasgow on the evening of April 8, amounting to no less than 12°·8; but it was of short duration, and comprised so completely within the interval from 9 A.M. to 9 P.M., as not to have affected either of these observations. While at Aberdeen, where the Depression had occurred earlier, and to the smaller extent of 6°·7 only, and lasted less than two hours,—its maximum had just struck on the 9 A.M. observation and made that appear excessive.

The Greenwich observations, very much as might have been expected from their great distance, were not sensibly affected by our peculiar Scottish phenomenon of April 8; but are extremely instructive for study, and the proof they give that 9 A.M. and 9 P.M. observations anywhere, are not sufficient for arriving at a knowledge of all the laws of Nature in this department of Meteorology.

PART II.

Thus far I have described only the simple results of rude, instantaneous observation, viz., the depression of the wet, below the dry, bulb thermometer as actually seen by the observer. And though that quantity by itself does not give the full or exact Hygrometric state of the atmosphere, it does show forth to so large an extent any variations in the same, that I could wish our Scottish bi-diurnal observers were instructed to enter that quantity, viz., the depression of the wet, below the dry, bulb, as they might so easily do, at the time they enter the latter.

For then, having only one column necessary to look at for instant Hygrometry, they would be far sharper in appreciating changes therein, and the final results their observations might lead to,—than when their present two columns of mere thermometer figures rather confuse them at the time, and are relegated to the Royal Observatory, Edinburgh, at the end of the month, for some one

there to find out by computations of another kind, what their instrumental readings were equivalent to touching "Humidity;" but on days then so long passed by, as to have ceased to have any vivid interest for the observer.

To bear on, or illustrate this proposition, all my graphic projections in Appendix II. have been arranged so as to give, *first*, the raw depression of the wet, below the dry, bulb; and *second*, the computed Humidity, taking account of the Temperature at the time; and it will be seen that there is no important abnormal wave in the latter, that has not its crest, or hollow sufficiently, and sometimes more strikingly, marked in the former. The former therefore, which every observer can enter for himself at the time with a living interest in it, is quite near enough to the scientific truth for all current weather discussions whether for agriculturists or gardeners, sailors or country gentlemen.

But in this particular inquiry of ours on the present occasion, we must do something more. Wherefore Mr HEATH, 1st Assistant Astronomer in the Royal Observatory, has obligingly assisted me by both computing three forms of the Hygrometric expression, and also projecting their curves, together with that of the Temperature, for all the hourly observations of the three continuously working Observatories alluded to.

Now the projection of the Humidities does not differ much, as already indicated, from the mere Depressions of the Wet Bulb. Nor does the projection of the Grains-weight of water in a cubic foot of air, except in the way of dulling and flattening all the curves. But the map of the Grains-weight of water still required to saturate each cubic foot, gives an immense result for our particular phenomenon of the night of April 8; as well as a notable insight into some permanent characteristics of climate.

These permanencies are, that in the North there is very little change between day and night either as to quantity of watery vapour in the air, or the further amount required to saturate it. But in the South, *teste* the Royal Observatory, Greenwich, there is an intensity of difference between day and night, not in the amount of watery vapour contained in the air, but in the further quantity which the air could take up without being saturated thereby,—which is not only surprising but warning too; as it is a condition that lies at the root of many of the movements of the atmosphere, and promotes also the disruptive, in place of the silent or slow, discharge of atmospheric electricity.

Looking next to the particular phenomenon of April 8, we find it occurred at 9 A.M. at Aberdeen; and at 4 P.M. at Glasgow; or crossed the country from N. East to S. West at the rate of about 14 miles per hour, increasing in quantity as it went; for while it attained to only 0·80 grains at Aberdeen during 2 hours, it reached 1·80 grains at Glasgow and lasted there for nearly 8 hours. That is, the increased number of grains of watery vapour *per* cubic foot, which the air could take up without being saturated.

Now as that is the very effect which is experienced in the South every day at Noon, as contrasted against Midnight, we might expect that our phenomenon was produced by an elevation of temperature in the air, without time given to it to pick up moisture equivalent to its then increased Humidity requirements. And this appears to have been the case to some extent, but was certainly preceded at Aberdeen on the morning of the 8th, where the influence began, by a very unusual decrease of the absolute amount of watery vapour contained in the air,—however that decrease was operated.

Hence in one way or another, dryness of the air was an eminent characteristic of the atmosphere though for a limited period, near, or about, or shortly preceding the time when the night clouds over Edinburgh appeared luminous by excess of brilliancy in their reflection of the city's gas-lights.

But what does that lead us to, as to the physical manner in which the reflection was produced?

Part III.

Before entering on this last portion of the inquiry, let me further state, that after many and many nights of clouds black on a gently translucent starry sky subsequent to April 8, 1882;—there was another most remarkable example of clouds bright on a black but still starry sky on Monday April 30, 1883. Those unnatural looking bright midnight clouds, as they were wafted hither and thither over the heavens by stray currents of air rather than regular winds, had almost a fearful splendour,—reminding one of Salvator Rosa's dark Noon-day pictures of white clouds overhanging deep rocky gorges among Calabrian mountains black as midnight and teeming with treacherous banditti; and I much wondered that honest Edinburgh folk were not out on the streets in crowds gazing at, and discussing the strange spectacle. So short-lived too; for the very next night was eminent for the normal blackness of its clouds contrasted against the pellucid and star-bearing heavens between them.

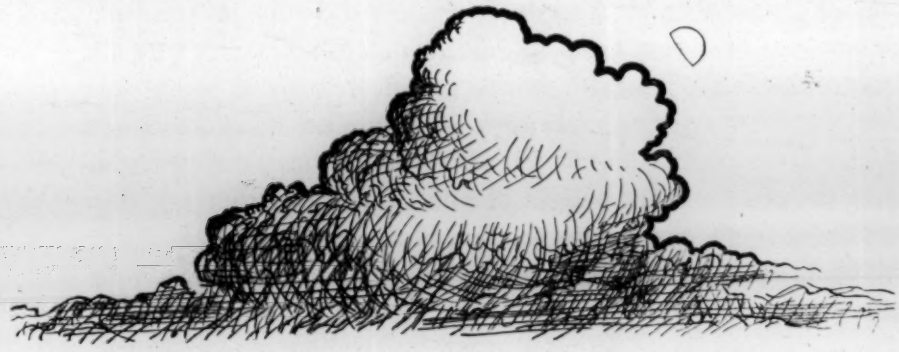
I wrote therefore to the Astronomer-Royal at Greenwich, inquiring whether any of the more wide-spreading influences, causes or accompaniments of Aurora, were manifested there, on the nights of April 8, 1882, and April 30, 1883, as compared with the nights and days immediately before and after these two dates. But the reply, as will be seen in Appendix 4, was entirely negative; for neither in Terrestrial Magnetism, Earth currents, atmospheric electricity, or Sun-spots was there anything noteworthy going on at either of those times.

Relieved therefore of any Cosmical phenomenon to attend to,—let us now look at the matter in its more ordinary terrestrial character.

On June 25, 1882, at the rather elevated station of Buxton, in high Derby-

shire, I witnessed a remarkable proof that "cumulus" clouds can assume, and keep up for a short time, an excessive brilliancy of reflection.

The case was this; at 6 P.M. when walking in the Park there, and looking S. East, I noted and sketched the half-Moon and a great thunder-cumulus* cloud close to it thus,



The Moon was exceedingly pale as compared with the great mass of the cloud on which the Sun was shining out of a clear sky in the West. The cloud was indeed estimated at 7 to 10 times as bright as the Moon! This extreme brightness of the cloud however only lasted about half an hour; when its brighter part went down to something like 3 times that of the Moon.

But as Sir JOHN HERSCHEL well remarked in his "Cape Observations," and when contrasting telescopically the brightness of the Moon setting behind the summit-cliff of Table Mountain, with that cliff then illuminated by the brilliant rising Sun of South Africa,—their then brightnesses were equal, just as their illuminations by the Sun, at the same distance therefrom in space, were equal also. But the solid surface of the Moon must be a nearly constant of reflecting power; therefore when it was so vastly transcended in brightness by the Buxton cloud in daylight,—the said cloud must have been an anomaly surpassing all ordinary terrestrial surface materials in reflective power, just as did the Edinburgh night clouds when distinctly luminous from their reflection of gas-lights far below them.

What enabled clouds then, on these two or three occasions, to reflect so very strongly whatever light, whether Solar, or artificial, that struck upon them? The only reason I can suggest powerful enough for the occasion, but one that seems to fulfil all the conditions, is,—that the molecules of the clouds were then in a hollow, vesicular condition, rather than drops or spherules of water. The former state is evidently most compatible with their floating in

* The thunder-cumulus, when weather is approaching a condition for electric discharge differs from the ordinary cumulus cloud, by being more tightly made up as it were, and with smaller or sort of cauliflower figures.

the air for any length of time and dropping no water; whereas the latter is the very preparation for rain-fall. This latter too is the condition of least reflection and most absorption of light, while the former is that of least absorption and most reflection.

These propositions may be practically established most easily by earth-surface examples, where the nature of the molecules may be most easily examined. Falling rain drops, even when directly shone on by the Sun and forming a rainbow, are anything but bright, unless indeed they are mixed with hail. And if we take water in the largest shape, what is there so dark as the deep blue sea, whence comes to our eyes only a faint, "first surface" reflection, from a sphere of stupendous size; and yet what is so brightly white as the foam of the same material when arranged in numerous, small coalescing convex vesicles, every one of them reflecting from both the first, and more especially the second, surface of its film, whatever point or gleam of light there may be in the whole hemisphere illuminating them.

Or again how dark brown is the water of a peaty hill in the Highlands when in a placid state, reflecting by means of only its first surface; and yet how brightly white is the course of a stream of it viewed from a distance on the mountain side and even under a cloudy sky, when it has to chafe and tumble down rocky channels, wherein it covers itself with foam, or innumerable little hemispherical bubbles on bubbles, each of which gives us, both the weak first, and the strong second, reflection of a film of water, or glass plate in air.

That is, such a frothy surface is bright when we look upon it from above, or the side whence, by day, comes its chief, or only illuminating light; as *snow* also then appears most intensely white. But when we look at either snow, or froth of water between us and the chief light, they appear dark rather than bright; for they reflect far too well, to allow much to be transmitted through them.

But still more particularly what can be brighter than those fields of apparent snow, the upper surfaces of the clouds composing the great cloud stratum of the low N. East, or commencing Trade, wind, as seen day after day in the summer season from the summit of the Peak of Teneriffe, at a depth of several thousand feet below: and they are known to be in the watery, as contra-distinguished to the frozen, condition. And yet what is darker and more threatening than the appearance of the same clouds, when seen from below, or between the observer and the Sun-illumined hemisphere of sky.

There too, at or near the sea level, in a moist air, rain does sometimes fall from those clouds' lower dark surfaces, where their component molecules may be increased in size with acquired outside moisture until they become practically drops of water. But above, on their upper surfaces, where to an observer

higher still, they appear so blindingly white, they come into contact with "the Teneriffe air above the clouds" (*i.e.*, the clouds of the lower N. East wind), which air is dry to the last degree; dry even to a depression of from 25 to 30 degrees Fahr. of the wet, below the dry, bulb Thermometer. Now this is a state of things which must evaporate the outside of the watery cloud-molecule; and if there be, as I believe has long since been generally held, a hollow or air centre to it, must leave the watery coating portion only as a thin shell surrounding such air particle. In which case such shell will reflect from a second surface almost as large as the first, and with a very minimum of absorption by fluid material.

Such thinning indeed of the vesicle, as pointed out lately by Professor ALEX. HERSCHEL, must not be carried too far; or, like the black centre of NEWTON'S rings, there will supervene an incapacity to reflect any light; immediately after which, the vesicle must burst, and cease to be a visible existency. As this termination of the life of cloud molecules—which are seen by travellers who ascend the peak, to be continually rising into the upper air, but never getting beyond a certain level therein,*—must take place more rapidly the drier the medium, it results that the whole cloud seen in the distance will have a harder, better defined ontline, on the side where the air is dry, than that where it is moist; or according to Nature's general law, above, rather than below, the level of the N. East wind's clouds.

Now the night clouds of April 8, 1882, which belonged to such N. East weather, showed well-compacted, almost case-hardened surfaces below, or when looked at from below, which was also at that time, the direction from which their chief illumination came, viz., the city gas-lights. And if their lower surfaces were then so compact, and could then reflect so powerfully, as they undoubtedly did that night, it must have been because there was at that time a stratum of air *below* them, as remarkably dry as the classic stratum which is

* This feature is well set forth by Dr MARCET, F.R.S., in his recent book *Southern and Swiss Health Resorts*, p. 262; except that he speaks of the return S. West current as being *immediately* above the cloud, in place of, as it is throughout all the summer season, separated from it by a thickness of full 5000 feet of a gradually decreasing strength of N. East wind, the same in direction as what prevails both below, and in, the cloud level, but differing hygrometrically therefrom exceedingly, in being extraordinarily dry. This important physical peculiarity is afterwards, however, fully acknowledged by Dr MARCET at pp. 296 to 306 of his useful book. For he there sets forth in a fuller and more serious manner that the N. East cloud level is never so low as 1200 feet, but nearer to 3000 feet high; and by its shade moderates both the temperature, the radiation and the moisture of the country below it. But at his Guajara station, 7090 feet high and therefore altogether above that N. East cloud level, he found there was still a prevailing tendency of the wind to blow from the North East, but accompanied by a terrific dryness, amounting on one occasion to 30°·5 depression of the wet, below the dry, bulb thermometer. Even on the higher central Peak, at 10,700 feet elevation, he says that "the S. West current, bringing back moisture from between the tropics," was only beginning to be felt; and the traveller would have to ascend several thousand feet higher still, if he could, to reach the full force and volume of that important stratum, at that season. All which exactly agrees with my own experience, described in *Teneriffe, an Astronomer's Experiment*, in 1856.

otherwise always above, any massive cumulus clouds, as testified by the Teneriffe observations of 27 years ago.

But the whole purport of the Meteorological data we have collected and discussed from 27 Observatories, large and small, shows without controversy that a most unusual wave of dryness did pass across Scotland on that particular 8th of April day. Below the level of the clouds too, because so distinctly perceived and felt on the inhabited surface of the earth; but having its maximum probably at 2000 feet or more above the sea-level, because recorded as greater in amount at the hill, than the valley (but everywhere beneath the clouds), stations of the Scottish Meteorological Society.

APPENDIX I.

Bi-Diurnal Observations from April 6–10, 1882, at 24 Stations of the Scottish Meteorological Society, and 3 Government Observatories.

Station.	Date. April 1882.	Barometer reduced to Sea-level and 68° F. at 9 A.M. and 9 P.M.	Hygrometer at 9 A.M. and 9 P.M. Dry Bulb.	Hygrometer at 9 A.M. and 9 P.M. Wet Bulb.	Hygrometrical Computed Results. Depression of Wet Bulb.	Weight of Vapour in 1 Cubic Foot of Air.	Vapour required to saturate 1 Cubic Foot of Air.	Humidity. Sat.=100.	Wind at 9 A.M. and 9 P.M. Direction.	Pressure in lbs. on the Square Foot.	Clouds. Direction.	Amount, 0–10.	Sunshine.	Ozone.	Rain.	Remarks.
		ins.	°	°	°	grs.	gr.						hrs.			
	6	30·54	42·7	41·8	0·9	3·0	0·2	93	E.	2·6	...	6·8	6·0	2	0·0	
		30·60	41·1	38·7	2·4	2·4	0·6	81	E.	2·2	...	...		...	...	
	7	30·67	43·2	40·8	2·4	2·6	0·6	81	E.	2·6	...	2·3	9·3	4	0·0	
Edinburgh, No. 1.		30·71	39·0	38·7	0·3	2·7	0·1	98	E.	2·9	...	...		...	...	
162 feet.	8	30·68	43·2	40·8	2·4	2·6	0·6	81	E.	2·2	...	0·5	10·8	0	0·0	
		30·67	39·2	38·3	0·9	2·6	0·2	93	N.E.	2·6	...	...		...	...	
Lat. 55° 57′ N. Long. 3° 11′ W.	9	30·52	38·7	36·7	2·0	2·3	0·5	84	S.E.	1·7	...	3·5	6·5	4	0·0	5 P.M. Fine display of cirri cloud over whole sky.
		30·37	36·7	35·7	1·0	2·3	0·2	92	S.E.	2·0	...	...		...	...	
	10	30·25	38·4	37·7	0·7	2·6	0·2	94	E.	2·2	...	3·5	6·5	0	0·0	
		30·17	36·9	34·7	2·2	2·0	0·5	82	E.	2·0	...	...		...	...	
Means, . .		30·52	39·9	38·4	1·5	2·5	0·4	88	...	2·3	...	...	...	...	...	
	6	30·52	39·7	37·9	1·8	2·4	0·5	86	N.E.	1·0	...	8	...	...	...	Clear and fair.
		30·57	35·0	34·3	0·7	2·2	0·2	93	N.E.	0·2	...	...	...	...	...	
	7	30·59	30·0	28·8	1·2	1·6	0·4	80	E.	0	...	Fog.	...	...	...	Do.
Braemar, No. 2.		30·64	36·9	33·5	3·4	1·8	0·8	73	E.	0	...	...	...	...	...	
1114 feet.	8	30·60	36·7	32·1	4·6	1·6	0·9	63	E.	0	...	...	...	...	...	Clear and fair.
		30·54	37·7	35·2	2·5	2·1	0·6	80	E	0	...	...	...	...	...	
Lat. 57° N. Long. 3° 24′ W.	9	30·41	37·7	32·5	5·2	1·6	1·1	61	E.	0	...	...	...	...	...	Clear and fair.
		30·31	39·4	36·7	2·7	2·2	0·6	79	E.	0	...	...	...	...	...	
	10	30·16	42·2	37·7	4·5	2·1	1·0	69	S.E.	0·2	...	3	...	...	...	Do.
		30·14	34·4	32·8	1·6	2·0	0·4	84	E.	0	...	1	...	...	...	
Means, . .		30·45	37·0	34·2	2·8	2·0	0·7	77	...	0·1	...	...	...	...	...	
	6	30·47	40·5	39·5	1·0	2·7	0·2	92	N.E.	4·0	...	Mist.	3	...	...	
		30·53	37·5	36·5	1·0	2·4	0·2	91	E.	4·0	...	Nimb.		...	...	
	7	30·60	40·5	38·1	2·4	2·4	0·6	81	S.E.	4·0	...	0	10	...	...	
North Esk Reservoir, No. 3.		30·63	32·5	31·5	1·0	1·9	0·2	88	E.	4·0	...	0		...	...	
1150 feet.	8	30·61	42·5	36·8	5·7	1·9	1·2	62	E.	4·0	...	0	12	...	...	Hoar frost.
		30·54	33·5	29·5	4·0	1·4	0·8	61	E.	4·0	...	0		...	...	Clear fine day.
Lat. 55° 48′ N. Long. 3° 21′ W.	9	30·43	32·1	31·5	0·6	2·0	0·1	92	S.E.	4·0	...	Fog.	7	...	...	Fog.
		30·29	31·5	29·5	2·0	1·6	0·6	74	N.	1·0	...	0		...	...	Cirro-stratus, fine.
	10	30·18	47·5	43·5	4·0	2·8	1·0	74	N.	1·0	...	0	12	...	...	
		30·10	35·5	33·5	2·0	2·0	0·4	82	Var.	4·0	...	5		...	...	
Means, . .		30·44	37·4	35·0	2·4	2·1	0·5	80	...	3·4	...	...	...	...	...	

Station.	Date. April 1882.	Barometer reduced to Sea-level and 68° F. at 9 A.M. and 9 P.M.	Hygrometer at 9 A.M. and 9 P.M. Wet Bulb.	Hygrometer at 9 A.M. and 9 P.M. Dry Bulb.	Hygrometrical Computed Results. Depression of Wet Bulb.	Weight of Vapour in 1 Cubic Foot of Air.	Vapour required to saturate 1 Cubic Foot of Air.	Humidity. Sat.=100.	Wind at 9 A.M. and 9 P.M. Direction.	Wind at 9 A.M. and 9 P.M. Pressure in lbs. on the Square Foot.	Clouds. Direction.	Clouds. Amount, 0–10.	Sunshine.	Ozone.	Rain.	Remarks.
		ins.	°	°	°	grs.	gr.						hrs.			
	6	30·39	41·1	40·1	1·0	2·7	0·3	92	E.	4·0	E.	10		…	…	
		30·48	39·0	36·4	2·6	2·2	0·6	80	E.	1·0	E.	2	12	…	…	
Wanlockhead,	7	30·55	42·9	38·5	4·4	2·2	1·0	70	E.	4·0	…	0		…	…	
No. 4.		30·58	37·0	36·5	0·5	2·4	0·2	96	E.	0·2	…	0	12	…	…	
1334 feet.	8	30·57	40·3	36·0	4·3	2·0	1·0	68	W.	0·2	…	0		…	…	
		30·47	40·5	33·7	6·8	1·5	1·4	53	S.W.	0·2	…	0	12	…	…	
Lat. 55° 24′ N.																
Long. 3° 48′ W.	9	30·40	30·2	29·9	0·3	1·9	0·1	95	W.	0·2	…	0		…	…	
		30·29	36·3	35·2	1·1	2·2	0·3	90	W.	0·2	W.	1	13	…	…	
	10	30·17	42·8	40·0	2·8	2·5	0·7	79	W.	0	…	1		…	…	
		30·08	36·1	36·0	0·1	2·5	0·0	99	N.W.	0	…	6	6	…	…	
Means, . .		30·40	38·6	36·2	2·4	2·2	0·6	82	…	1·0	…	…	…	…	…	
	6	30·49	43·	39·	4·	2·3	0·9	71	E.	9·0	E.	10		…	…	
		30·57	43·	42·	1·	2·9	0·3	92	E.	9·0	E.	8	3	…	…	
Marchmont	7	30·66	41·	39·	2·	2·5	0·5	84	E.	1·0	E.	8		…	…	
(Berwick),		30·66	38·	37·	1·	2·4	0·3	91	E.	4·0	…	0	6	…	…	
No. 5.	8	30·67	41·	39·	2·	2·5	0·5	84	E.	1·0	…	0		…	…	
500 feet.		30·59	39·	38·	1·	2·5	0·3	92	E.	4·0	E.	10	8	…	…	
Lat. 55° 44′ N.																
Long. 2° 25′ W.	9	30·50	39·	36·	3·	2·1	0·7	77	E.	1·0	E.	10		…	…	
		30·34	34·	34·	0·	2·3	0·0	100	E.	4·0	E.	5	8	…	…	
	10	30·24	35·	34·	1·	2·1	0·3	90	N.E.	4·0	N.E.	10		…	…	
		30·14	36·	35·	1·	2·2	0·3	91	N.E.	4·0	N.E.	10	4	…	…	
Means, . .		30·49	38·9	37·3	1·6	2·4	0·4	87	…	4·1	…	…	…	…	…	
	6	30·54	45·7	41·3	4·4	2·5	1·0	70	N.E.	…	…	…	…	…		
		30·60	43·0	40·5	2·5	2·6	0·6	81	N.E.	…	…	…	…	…		
Dalkeith,	7	30·68	45·3	41·5	3·8	2·6	0·9	74	N.E.	…	…	…	…	…		
No. 6.		30·68	39·5	38·5	1·0	2·6	0·2	92	N.E.	…	…	…	…	…		
190 feet.	8	30·69	45·5	42·0	3·5	2·6	0·8	75	N.E.	…	…	…	…	…		
		30·61	37·0	35·5	1·5	2·2	0·4	87	N.	…	…	…	…	…		
Lat. 55° 54′ N.															No Rain.	
Long. 3° 4′ W.	9	30·52	39·5	37·5	2·0	2·3	0·5	84	E.	…	…	…	…	…		
		30·36	36·0	35·5	0·5	2·4	0·1	96	E.N.E.	…	…	…	…	…		
	10	30·26	38·5	37·7	0·8	2·6	0·2	94	E.S.E.	…	…	…	…	…		
		30·18	37·3	35·5	1·8	2·2	0·5	85	W.	…	…	…	…	…		
Means, . .		30·51	40·7	38·6	2·2	2·5	0·5	84	…	…	…	…	…	…	…	
	6	30·50	44·5	43·2	1·3	3·0	0·3	90	E.	…	…	8		7		
		30·61	42·3	40·2	2·1	2·6	0·5	84	E.	…	…	8	1	6	0·10	
Smeaton,	7	30·67	44·5	42·2	2·3	2·8	0·6	83	E.	…	…	3		6	…	
No. 7.		30·68	38·0	37·0	1·0	2·4	0·3	91	E.	…	…	3	7	5	…	
100 feet.	8	30·70	44·5	42·7	1·8	2·9	0·5	87	E.	…	…	2		4	…	
		30·63	37·5	36·2	1·3	2·3	0·3	89	E.	…	…	3	8	3	…	
Lat. 56° 3′ N.																
Long. 2° 40′ W.	9	30·51	40·5	38·2	2·3	2·4	0·6	82	E.	…	…	8		4	…	
		30·39	36·5	35·2	1·3	2·2	0·3	89	E.	…	…	1	8	6	…	
	10	30·27	39·0	38·2	0·8	2·6	0·2	94	E.	…	…	6		4	…	
		30·19	33·5	32·8	0·7	2·1	0·1	92	E.	…	…	2	5	5	…	
Means, . .		30·52	40·1	38·6	1·5	2·5	0·4	88	…	…	…	…	…	…	…	

Station.	Date. April 1882.	Barometer reduced to Sea-level, and 68° F. at 9 A.M. and 9 P.M.	Hygrometer at 9 A.M. and 9 P.M.		Hygrometrical Computed Results.				Wind at 9 A.M. and 9 P.M.		Clouds.		Sunshine.	Ozone.	Rain.	Remarks.
			Dry Bulb.	Wet Bulb.	Depression of Wet Bulb.	Weight of Vapour in 1 Cubic Foot of Air.	Vapour required to saturate 1 Cubic Foot of Air.	Humidity. Sat. = 100.	Direction.	Pressure in lbs. on the Square Foot.	Direction.	Amount, 0-10.				
		ins.	°	°	°	grs.	gr.						hrs.			
East Linton, No. 8.	6	30·53	43·0	40·5	2·5	2·6	0·6	81	E.	0·2	E.	4	10	6	0·10	
		30·57	44·8	39·3	5·5	2·2	1·3	63	E.	0·2	...	10		4	...	
	7	30·67	46·0	43·0	3·0	2·8	0·8	79	E.	0·2	E.	2	12	4	...	
90 feet.		30·67	39·0	37·0	2·0	2·3	0·5	84	E.	0·2	...	...		6	...	
	8	30·67	46·2	43·5	2·7	2·9	0·7	82	E.	0·2	...	2	10	5	...	
Lat. 55° 59′ N. Long. 2° 16′ W.		30·62	38·0	36·0	2·0	2·2	0·5	83	E.	0·2	E.	8		4	...	
	9	30·51	41·0	37·9	3·1	2·3	0·7	76	N.E.	0·2	...	7	0	8	...	
		30·35	36·3	33·5	2·8	1·9	0·7	76	E.	0·0	...	1		3	...	
	10	30·25	40·0	38·0	2·0	2·4	0·5	84	E.	0·2	...	2	10	3	...	
		30·15	35·5	32·8	2·7	1·8	0·6	76	W.	0·0	...	2		6	...	
Means, . .		30·50	41·0	38·2	2·8	2·3	0·7	78	...	0·2	...	...	...	...	...	
This Station's results are rejected in the present Inquiry.																
Haddington, No. 9.	6	30·52	44·2	43·7	0·5	3·2	0·1	96	S.E.	1·0	...	8·	...	...	...	
		30·61	41·2	40·5	0·7	2·8	0·2	95	E.	1·0	...	9·	...	...	0·01	
	7	30·66	46·0	44·5	1·5	3·2	0·4	89	E.	1·0	...	4·	...	...	...	
240 feet.		30·67	38·5	39·0	? (+0·5)	...	...	...	E.	1·0	...	0·	...	...	...	
	8	30·68	45·2	44·0	1·2	3·1	0·4	91	E.N.E.	1·0	...	3·	...	...	...	
Lat. 55° 57′ N. Long. 2° 47′ W.		30·58	36·2	37·0	? (+0·8)	...	...	...	E.	1·0	...	0·	...	...	...	
	9	30·49	48·5	48·2	0·3	3·8	0·1	98	E.N.E.	1·0	...	6·	...	...	...	
		30·35	36·5	36·5	0·0	2·5	0·0	100	N.E.	1·0	...	0·	...	...	...	
	10	30·21	43·2	44·2	? (+1·0)	...	...	...	E.	1·0	...	7·	...	...	...	
		30·16	36·0	35·2	0·8	2·3	0·2	93	E.	1·0	...	0·	...	...	...	
Means, . .		30·49	41·6	41·3	0·3	...	...	...	...	1·0	...	...	...	...	...	
Stobo Castle, No. 10.	6	30·47	42·0	41·0	1·0	2·8	0·3	92	E.	...	...	...	...	...	No Rain.	
		30·57	40·0	38·0	2·0	2·4	0·5	84	E.	...	...	...	...	...		
	7	30·61	42·0	40·0	2·0	2·6	0·5	85	E.	...	...	...	...	...		
600 feet.		30·65	38·0	36·0	2·0	2·2	0·5	83	E.	...	...	...	...	...		
	8	30·63	40·0	33·0	7·0	1·5	1·4	51	N.W	...	...	...	...	...		
Lat. 55° 35′ N. Long. 3° 25′ W.		30·55	36·0	35·0	1·0	2·2	0·3	91	E.	...	...	...	...	...		
	9	30·49	36·0	33·0	3·0	1·8	0·7	74	E.	...	...	...	...	...		
		30·33	34·0	33·0	1·0	2·1	0·2	89	E.	...	...	...	...	...		
	10	30·20	40·0	32·0	8·0	1·4	1·5	46	S.	...	...	...	...	...		
		30·13	39·0	37·0	2·0	2·3	0·5	84	E.	...	...	...	...	...		
Means, . .		30·46	38·7	35·8	2·9	2·1	0·6	78	...	...	...	...	...	...	...	
This Station's results are rejected in the present Inquiry.																
Cupar (Fife), No. 11.	6	30·54	44·	43·	1·0	3·0	0·3	92	E.	4·0	...	...	...	...	No Rain.	
		30·52	45·	44·	1·0	3·1	0·3	92	E.	1·0	...	...	...	...		
	7	30·69	44·	43·	1·0	3·0	0·3	92	E.	1·0	...	...	...	...		
210 feet.		30·69	45·	43·	2·0	2·9	0·5	85	E.	1·0	...	...	...	...		
	8	30·71	45·	44·	1·0	3·1	0·3	92	E.	1·0	...	...	...	...		
Lat. 56° 10′ N. Long. 3° 6′ W.		30·63	46·	44·	2·0	3·1	0·5	86	E.	1·0	...	...	...	...		
	9	30·49	37·	36·	1·0	2·3	0·3	91	E.	1·0	...	...	...	...		
		30·36	38·	37·	1·0	2·4	0·3	91	E.	1·0	...	...	...	...		
	10	30·26	38·	36·	2·0	2·2	0·5	83	E.	1·0	...	...	...	...		
		30·17	39·	38·	1·0	2·5	0·3	92	E.	1·0	...	...	...	...		
Means, . .		30·51	42·1	40·8	1·3	2·8	0·4	90	...	1·3	...	...	...	...		

Station.	Date. April 1882.	Barometer reduced to Sea-level and 68° F. at 9 A.M. and 9 P.M.	Hygrometer at 9 A.M. and 9 P.M. Dry Bulb.	Hygrometer at 9 A.M. and 9 P.M. Wet Bulb.	Hygrometrical Computed Results. Depression of Wet Bulb.	Weight of Vapour in 1 Cubic Foot of Air.	Vapour required to saturate 1 Cub e Foot of Air.	Humidity. Sat.=100.	Wind at 9 A.M. and 9 P.M. Direction.	Pressure in lbs. on the Square Foot.	Clouds. Direction.	Amount, 0-10.	Sunshine.	Ozone.	Rain.	Remarks.
		ins.	°	°	°	grs.	gr.						hrs.			
	6	30·50	45·0	43·0	2·0	2·9	0·5	85	E.S.E.	9·0	...	...	...	...		
		30·57	42·5	39·5	3·0	2·4	0·7	78	E.S.E.	4·0	...	...	...	...		
Glasgow,	7	30·64	44·5	41·0	3·5	2·6	0·8	74	E.	4·0	...	...	...	...		
No. 12.		30·67	40·5	38·0	2·5	2·4	0·6	80	S.E.	1·0	...	...	...	...		
54 feet.	8	30·67	44·0	41·0	3·0	2·6	0·7	77	E.	4·0	...	...	...	...		
		30·60	41·5	36·5	5·0	2·0	1·1	65	E.	1·0	...	...	...	...		
Lat. 55° 53′ N.	9	30·51	39·5	37·0	2·5	2·2	0·6	80	E.S.E.	1·0	...	...	...	...		
Long. 4° 18′ W.		30·34	41·5	40·0	1·5	2·6	0·4	89	E.S.E.	1·0	...	...	...	...	No Rain.	
	10	30·23	34·0	34·0	0·0	2·3	0·0	100	S.S.E.	0·2	...	...	...	...		
		30·14	39·5	37·5	2·0	2·4	0·5	84	E.S.E.	0·2	...	...	...	...		
Means, . .		30·49	41·2	38·7	2·5	2·4	0·6	81	...	2·5	...	...	...	...		
	6	30·53	45·5	44·1	1·4	3·1	0·4	89	N.E.	9·0	...	...	8	...		
		30·63	41·7	39·1	2·6	2·4	0·6	81	N.E.	9·0	...	...		...		
Balloch Castle,	7	30·67	44·5	41·6	2·9	2·7	0·7	78	N.E.	4·0	...	...	11	...		
No. 13.		30·71	40·5	38·6	1·9	2·5	0·5	85	E.	4·0	...	...		...		
93 feet.	8	30·70	46·0	40·6	5·4	2·3	1·3	67	N.E.	4·0	...	...	12	...		
		30·63	41·0	38·6	2·4	2·4	0·6	81	E.	0·0	...	...		...		
Lat. 56° 1′ N.	9	30·54	37·0	35·8	1·2	2·3	0·3	89	E.	0·0	...	...	10	...		
Long. 4° 35′ W.		30·39	47·5	45·6	1·9	3·2	0·5	87	S.E.	0·0	...	...		...		
	10	30·27	37·0	36·6	0·4	2·5	0·1	96	S.E.	0·0	...	...	7	...		
		30·18	41·5	39·8	1·7	2·6	0·4	87	S.E.	0·0	...	...		...		
Means, . .		30·52	42·2	40·0	2·2	2·6	0·5	84	...	3·0	...	...	...	...	...	
	6	30·48	42·1	41·6	0·5	3·0	0·1	96	E.	...	...	...	...	...	...	
		30·55	37·1	36·1	1·0	2·3	0·3	91	...	...	...	...	...	...	...	
Castle-Douglas,	7	30·61	36·1	35·1	1·0	2·2	0·3	91	N.E.	...	...	...	...	...	...	
No. 14.		30·65	35·1	34·1	1·0	2·1	0·3	90	...	...	...	...	...	...	...	
783 feet.	8	30·64	38·1	37·1	1·0	2·4	0·3	91	N.	...	...	...	...	...	...	
		30·56	35·1	34·1	1·0	2·1	0·3	90	...	...	...	...	...	...	...	
Lat. 55° 35′ N.	9	30·45	31·6	30·1	1·5	1·6	0·5	81	N.E.	...	...	...	...	...	...	
Long. 3° 52′ W.		30·35	37·1	36·1	1·0	2·3	0·3	91	...	...	...	...	...	...	...	
	10	30·24	33·1	32·1	1·0	2·0	0·2	89	S.	...	...	...	...	...	...	
		30·14	34·1	33·1	1·0	2·1	0·2	89	...	...	...	...	...	...	...	
Means, . .		30·47	36·0	35·0	1·0	2·2	0·3	90	...	...	...	...	...	...	...	
	6	...	45·8	43·0	2·8	2·8	0·7	80	...	...	...	...	...	...	...	
		30·54	42·0	39·0	3·0	2·4	0·7	78	...	...	...	...	...	...	...	
Moffat,	7	30·62	46·8	46·2	0·6	3·5	0·2	96	...	...	...	...	...	...	...	
No. 15.		30·63	43·0	42·8	0·2	3·1	0·1	98	...	...	...	...	...	...	...	
350 feet.	8	30·61	53·0	53·0	0·0	4·5	0·0	100	...	...	...	...	...	...	...	
		30·54	42·8	36·0	6·8	1·7	1·5	56	...	...	...	...	...	...	...	
Lat. 55° 21′ N.	9	30·48	43·5	38·0	5·5	2·0	1·2	62	...	...	...	...	...	...	...	Hard frost at night.
Long. 3° 27′ W.		30·35	40·0	38·0	2·0	2·4	0·5	84	...	...	...	...	...	...	...	
	10	30·22	45·0	42·8	2·2	2·9	0·5	84	...	...	...	...	...	...	...	
		30·11	40·5	30·5	10·0	1·1	1·8	38	...	...	...	...	...	...	...	
Means, .		30·46	44·2	40·9	3·3	2·6	0·7	78	...	...	...	...	...	...	...	

This Station's results are rejected in the present inquiry.

Station.	Date, April 1882.	Barometer reduced to Sea-level and 68° F. at 9 A.M. and 9 P.M.	Hygrometer at 9 A.M. and 9 P.M.		Hygrometrical Computed Results.				Wind at 9 A.M. and 9 P.M.		Clouds.		Sunshine.	Ozone.	Rain.	Remarks.
			Dry Bulb.	Wet Bulb.	Depression of Wet Bulb.	Weight of Vapour in 1 Cubic Foot of Air.	Vapour required to saturate 1 Cubic Foot of Air.	Humidity. Sat. = 100.	Direction.	Pressure in lbs. on the Square Foot.	Direction.	Amount, 0–10.				
		ins.	°	°	°	grs.	gr.						hrs.			
Stronvar, No. 16.	6	30·52	44·	41·	3·	2·6	0·7	77	E.	4·0	...	...	...	...	...	
		30·59	39·	36·	3·	2·1	0·7	77	...	...	...	...	...	...	...	
	7	30·66	42·	39·	3·	2·4	0·7	78	E.	0·2	...	...	...	...	...	
		30·64	37·	35·	2·	2·1	0·5	83	...	...	...	...	...	...	...	
428 feet.	8	30·66	42·	38·	4·	2·2	0·9	72	E.	1·0	...	...	...	...	...	
		30·57	36·	34·	2·	2·0	0·5	82	...	...	...	...	...	...	...	
Lat. 56° 20′ N. Long. 4° 20 W.	9	30·49	32·	31·	1·	1·9	0·2	87	E.	0·2	...	...	...	...	—	
		30·33	34·	33·	1·	2·1	0·2	89	...	...	...	...	...	...	...	
	10	30·23	36·	35·	1·	2·2	0·3	91	N.E.	1·0	...	...	...	...	...	
		30·13	42·	39·	3·	2·4	0·7	78	...	...	...	...	...	...	...	
Means, . .		30·48	38·4	36·1	2·3	2·2	0·5	81	...	...	...	...	...	...	...	
Greenock, No. 17.	6	30·51	44·2	42·2	2·0	2·8	0·5	84	E.	2·2	...	10	...	...	...	
		30·54	47·2	42·7	4·5	2·6	1·1	70	E.	1·0	...	0	...	...	...	
	7	30·64	42·2	38·7	3·5	2·3	0·8	75	E.	2·2	...	5	...	...	...	
		30·61	53·2	46·7	6·5	2·8	1·7	62	E.	0·2	...	0	...	...	...	
233 feet.	8	30·66	43·2	37·9	5·3	2·1	1·2	63	E.	2·2	...	5	...	...	...	
		30·57	55·2	42·9	12·3	1·9	3·1	40	E.	1·0	...	0	...	...	...	
Lat. 55° 57′ N. Long. 4° 45′ W.	9	30·52	36·0	33·9	2·1	2·0	0·5	81	E.	0·2	...	10	...	...	...	
		30·35	49·0	44·9	4·1	2·9	1·1	72	W.	1·0	...	0	...	...	...	
	10	30·22	37·2	36·7	0·5	2·5	0·1	96	E.	1·0	...	Nimb.	...	...	...	
		30·14	48·2	43·7	4·5	2·7	1·1	70	E.	0·2	...	5	...	...	...	
Means, . .		30·48	45·6	41·0	4·5	2·5	1·1	71	...	1·1	...	...	...	...	...	
Paisley, No. 18.	6	30·49	45·1	42·1	3·0	2·7	0·7	78	E.	...	...	10	6	...	...	
		30·56	43·6	39·1	4·5	2·3	1·0	68	E.	...	...	...		...	...	
	7	30·62	44·1	39·6	4·5	2·3	1·0	65	E.	...	...	10	11	...	...	
		30·65	42·6	38·1	4·5	2·2	1·0	69	S.E.	...	...	...		...	...	
88 feet.	8	30·65	37·6	36·1	1·5	2·3	0·4	87	S.E.	...	...	10	10	...	...	
		30·56	42·6	37·6	5·0	2·1	1·1	66	E.	...	...	...		...	...	
Lat. 55° 50′ N. Long. 4° 27 W.	9	30·48	39·1	36·1	3·0	2·1	0·7	77	E.	...	...	10	9	...	...	
		30·43	43·6	40·1	3·5	2·5	0·8	74	N.E.	...	...	...		...	...	
	10	30·21	35·1	32·1	3·0	1·7	0·7	72	E.	...	...	10	8	...	...	
		30·14	41·1	38·6	2·5	2·4	0·8	81	E.	...	...	...		...	...	
Means, . .		30·48	41·4	38·0	3·5	2·3	0·8	74	...	...	...	...	...	...	...	
Callton-Moe, No. 19.	6	30·48	52·0	47·0	5·0	3·0	1·4	69	E.	1·0	...	2	6	...	...	
		30·57	37·5	36·0	1·5	2·2	0·4	87	N.E.	1·0	...	0		...	...	
	7	...	49·0	43·0	6·0	2·5	1·5	62	E.	1·0	...	1	6	...	...	
		30·65	41·5	39·0	2·5	2·4	0·6	81	E.	1·0	...	0		...	...	
135 feet.	8	30·63	54·5	41·5	13·0	1·8	3·0	38	E.	1·0	...	0	10	...	...	
		30·55	42·5	41·5	1·0	2·9	0·2	92	N.E.	1·0	...	0		...	...	
Lat. 56° 5′ N. Long. 5° 28′ W.	9	30·48	45·5	40·0	5·5	2·2	1·2	64	E.	1·0	...	0	10	...	...	
		30·34	37·5	36·0	1·5	2·2	0·4	87	E.	1·0	...	0		...	...	
	10	30·23	47·5	45·0	2·5	3·1	0·6	83	E.	1·0	...	2	8	...	...	
		30·12	36·5	35·0	1·5	2·2	0·4	87	N.	1·0	...	0		...	...	
Means, . .		30·45	44·4	40·4	4·0	2·4	1·0	75	...	1·0	...	...	...	...	...	

Station.	Date. April 1882.	Barometer reduced to Sea-level and 65° F. at 9 A.M. and 9 P.M.	Hygrometer at 9 A.M. and 9 P.M. Dry Bulb.	Hygrometer at 9 A.M. and 9 P.M. Wet Bulb.	Hygrometrical Computed Results. Depression of Wet Bulb.	Weight of Vapour in 1 Cubic Foot of Air.	Vapour required to saturate 1 Cubic Foot of Air.	Humidity. Sat.=100.	Wind at 9 A.M. and 9 P.M. Direction.	Wind at 9 A.M. and 9 P.M. Pressure in lbs. on the Square Foot.	Clouds. Direction.	Clouds. Amount, 0–10.	Sunshine.	Ozone.	Rain.	Remarks.
		ins.	°	°	°	grs.	gr.						hrs.			
Eallabus, No. 20.	6 A.M.	30·48	45·	42·	3·	2·7	0·7	78	E.	1·0	...	...	...	...	...	
	6 P.M.	30·53	43·	40·	3·	2·5	0·7	78	E.	1·0	...	...	...	...	...	
	7 A.M.	30·61	47·	42·	5·	2·5	1·2	67	E.	1·0	...	...	...	...	...	
	7 P.M.	30·62	47·	43·	4·	2·7	1·0	73	E.	9·0	...	...	...	...	...	
71 feet.	8 A.M.	30·61	49·	41·	8·	2·1	1·9	53	E.	9·0	...	...	...	...	...	
	8 P.M.	30·51	45·	40·	5·	2·3	1·1	66	E.	1·0	...	...	...	...	...	
Lat. 55° 47′ N. Long. 6° 15′ W.	9 A.M.	30·46	53·	44·	9·	2·3	2·2	51	Calm.	0·0	...	...	...	...	...	
	9 P.M.	30·35	36·	35·	1·	2·2	0·3	91	Calm.	0·0	...	...	...	...	...	
	10 A.M.	30·25	43·	43·	0·	3·2	0·0	100	Calm.	0·0	...	...	...	...	...	
	10 P.M.	30·12	38·	37·	1·	2·4	0·3	91	Calm.	0·0	...	...	...	...	...	
Means, . .		30·45	44·6	40·7	3·9	2·5	0·9	75	...	2·2	...	...	...	...	...	
Gordon Castle, No. 21.	6 A.M.	30·56	45·5	42·6	2·9	2·8	0·7	79	S.E.	...	...	...	...	.	No Rain.	
	6 P.M.	30·60	38·1	36·0	2·1	2·2	0·5	82	S.E.	...	...	...	...	...		
	7 A.M.	30·64	44·8	40·0	4·8	2·3	1·1	67	S.W.	...	...	...	...	...		
	7 P.M.	30·64	43·0	36·5	6·5	1·8	1·4	56	S.W.	...	...	...	...	...		
104 feet.	8 A.M.	30·65	48·9	41·0	7·9	2·1	1·9	53	S.W.	...	...	...	...	...		Aurora.
	8 P.M.	30·56	39·1	37·0	2·1	2·3	0·5	83	S.W.	...	...	...	...	...		
Lat. 57° 38′ N. Long. 3° 2′ W.	9 A.M.	30·47	37·0	32·1	4·9	1·6	1·0	62	S.W.	...	...	...	...	...		
	9 P.M.	30·36	35·0	33·5	1·5	2·0	0·4	85	S.W.	...	...	...	...	...		
	10 A.M.	30·24	42·8	39·3	3·5	2·4	0·8	74	N.W.	...	...	...	...	...		
	10 P.M.	30·14	38·5	37·0	1·5	2·4	0·4	88	N.W.	...	..	...	...	.		
Means, . .		30·49	41·3	37·5	3·8	2·2	0·9	73	...	...	...	...	...	...	...	
New Pitsligo, No. 22.	6 A.M.	30·56	42·1	40·7	1·4	2·7	0·4	89	S.E.	...	...	...	...	...	...	
	6 P.M.	30·60	39·0	38·0	1·0	2·5	0·3	92	S.E.	...	...	...	...	...	...	
	7 A.M.	30·65	41·4	40·4	1·0	2·8	0·3	92	S.	...	...	...	...	...	...	
	7 P.M.	30·67	35·6	35·2	0·4	2·4	0·2	96	S.	...	...	...	...	...	...	
495 feet.	8 A.M.	30·65	47·4	44·8	2·6	3·1	0·6	82	S.	...	...	...	...	...	...	
	8 P.M.	30·58	36·8	36·0	0·8	2·4	0·2	93	S.E.	...	...	...	...	...	...	
Lat. 57° 35′ N. Long. 2° 9′ W.	9 A.M.	30·48	38·3	37·3	1·0	2·5	0·3	92	S.E.	...	...	...	...	...	...	
	9 P.M.	30·33	33·8	33·1	0·7	2·0	0·2	93	S.	...	...	...	...	...	...	
	10 A.M.	30·23	37·3	36·0	1·3	2·3	0·4	89	E.	...	...	...	...	...	0·03	
	10 P.M.	30·14	38·0	36·3	1·7	2·3	0·4	85	N.W.	...	...	...	...	...		
Means, . .		30·49	39·0	37·8	1·2	2·5	0·3	90	...	...	...	...	...	...	...	
Inverness, No. 23.	6 A.M.	30·59	40·0	38·0	2·0	2·4	0·5	84	E.	...	...	0	10	2	No Rain.	
	6 P.M.	30·55	47·0	45·0	2·0	3·2	0·5	86	E.	...	...	0		6		
	7 A.M.	30·68	37·0	35·5	1·5	2·2	0·4	87	W.	...	...	10	8	4		
	7 P.M.	30·79	44·0	43·0	1·0	3·0	0·3	92	N.E.	...	...	0		6		
114 feet.	8 A.M.	30·64	41·0	39·0	2·0	2·5	0·5	84	N.E.	...	...	0	11	0		
	8 P.M.	30·57	43·0	41·0	2·0	2·7	0·5	84	E.	...	...	10		4		
Lat. 57° 28′ N. Long. 4° 13′ W.	9 A.M.	30·46	38·0	37·5	0·5	2·5	0·2	96	S.W.	...	...	10	4	6		
	9 P.M.	30·34	39·0	38·0	1·0	2·5	0·3	92	S.W.	...	...	0		4		
	10 A.M.	30·27	38·0	36·0	2·0	2·2	0·5	83	N.E.	...	...	10	2	6		
	10 P.M.	30·14	46·0	41·0	5·0	2·4	1·2	67	E.	...	...	0		8		
Means, . .		30·50	41·3	39·4	1·9	2·6	0·5	86	...	...	...	...	...	...	...	

Station.	Date. April 1882.	Barometer reduced to Sea-level and 68° F. at 9 A.M. and 9 P.M.	Hygrometer at 9 A.M. and 9 P.M. Dry Bulb.	Hygrometer at 9 A.M. and 9 P.M. Wet Bulb.	Hygrometrical Computed Results. Depression of Wet Bulb.	Weight of Vapour in 1 Cubic Foot of Air.	Vapour required to saturate 1 Cubic Foot of Air.	Humidity. Sat.=100.	Wind at 9 A.M. and 9 P.M. Direction.	Pressure in lbs. on the Square Foot.	Clouds. Direction.	Amount, 0-10.	Sunshine.	Ozone.	Rain.	Remarks.
		ins.				grs.	gr.						hrs.			
Aberdeen, No. 24.	6	30·59	45·8	43·2	2·6	2·9	0·7	82	S.E.	0·2	...	...	3	...	...	
		30·63	42·9	40·4	2·5	2·6	0·6	82	...	...	...	4		...	...	
	7	30·68	44·5	41·3	3·2	2·6	0·7	76	...	...	...		2	...	...	
		30·70	41·0	39·8	1·2	2·7	0·3	90	...	...	...	2		...	...	
66 feet.	8	30·68	39·7	36·8	2·9	2·2	0·7	78	...	...	...	8	9	...	...	
		30·60	41·5	39·2	2·3	2·5	0·6	83	...	...	...	9	10	...	...	
Lat. 57° 9′ N. Long. 2° 6′ W.	9	30·49	40·3	38·2	2·1	2·4	0·5	84	...	...	...	10		...	...	
		30·36	38·2	37·0	1·2	2·4	0·3	90	S.E.	1·0	...	4	10	...	...	
	10	30·25	39·0	37·6	1·4	2·4	0·4	89	N.	1·0	...	10		...	...	
		30·16	42·6	39·1	3·5	2·3	0·8	74	N.	0·2	...	10	...	...	...	
Means, . .		30·51	41·6	39·3	2·3	2·5	0·6	83	...	...	...	...	...	...	...	
Aberdeen Meteorological Council Observatory, No. 25.	6	30·	43·6	41·7	1·9	2·8	0·5	85	...	...	...	...	...	...	...	
		30·	41·6	39·4	2·2	2·5	0·5	84	...	...	...	...	...	...	...	
	7	30·	43·2	40·4	2·8	2·6	0·7	79	...	...	...	...	...	...	...	
		30·	39·5	38·6	0·9	2·6	0·2	93	...	...	...	...	...	...	...	
	8	30·	40·2	33·6	6·6	1·5	1·4	54	...	...	...	...	...	...	...	
		30·	40·7	38·9	1·8	2·5	0·5	86	...	...	...	...	...	...	...	
Lat. 57° 9′ N. Long. 2° 6′ W.	9	30·	39·7	37·7	2·0	2·4	0·5	84	...	...	...	...	...	...	...	
		30·	38·9	37·4	1·5	2·4	0·4	88	...	...	...	...	...	...	...	
	10	30·	37·7	36·7	1·0	2·4	0·2	92	...	...	...	...	...	...	...	
		30·	41·1	38·2	2·9	2·3	0·7	78	...	...	...	...	...	...	...	
Means, . .		...	40·6	38·3	2·4	2·4	0·6	82	...	...	...	...	...	...	...	
Glasgow Meteorological Council Observatory, No. 26.	6	30·	45·0	42·8	2·2	2·9	0·5	84	...	...	...	...	...	...	...	
		30·	42·9	39·9	3·0	2·5	0·7	78	...	...	...	...	...	...	...	
	7	30·	43·4	40·4	3·0	2·5	0·7	78	...	...	...	...	...	...	...	
		30·	42·0	39·3	2·7	2·5	0·6	80	...	...	...	...	...	...	...	
	8	30·	42·8	40·0	2·8	2·5	0·7	79	...	...	...	...	...	...	...	
		30·	41·8	39·8	2·0	2·6	0·5	86	...	...	...	...	...	...	...	
Lat. 55° 53′ N. Long. 4° 18′ W.	9	30·	39·2	36·8	2·4	2·2	0·6	81	...	...	...	...	...	...	...	
		30·	42·7	40·1	2·6	2·6	0·6	81	...	...	...	...	...	...	...	
	10	30·	33·0	33·0	0·0	2·2	0·0	100	...	...	...	...	...	...	...	
		30·	40·0	37·6	2·4	2·3	0·6	81	...	...	...	...	...	...	...	
Means, . .		...	41·3	39·0	2·3	2·5	0·6	83	...	...	...	...	...	...	...	
Royal Observatory, Greenwich (London). No. 27.	6	30·	48·4	46·3	2·1	3·28	0·56	85	...	...	...	...	...	...	...	
		...	44·3	42·0	2·3	2·77	0·56	82	...	...	...	...	...	...	...	
	7	30·	51·0	47·4	3·6	3·22	0·98	76	...	...	...	...	...	...	...	
		...	45·7	43·0	2·7	2·83	0·71	81	...	...	...	...	...	...	...	
— feet.	8	30·	53·0	49·2	3·8	3·44	1·06	75	...	...	...	...	...	...	...	
		...	44·9	42·2	2·7	2·75	0·64	80	...	...	...	...	...	...	...	
Lat. 51° 29′ N. Long. 0° 0′	9	30·	48·3	45·1	3·2	3·00	0·86	78	...	...	...	...	...	...	...	
		...	41·0	39·4	1·6	2·59	0·42	87	...	...	...	...	...	...	...	
	10	30·	46·9	44·3	2·6	2·98	0·71	82	...	...	...	...	...	...	...	
		...	43·8	41·2	2·6	2·66	0·62	80	...	...	...	...	...	...	...	
Means, . .		...	46·7	44·0	2·7	2·95	0·71	81	...	...	...	...	...	...	...	

APPENDIX II.

PROJECTIONS of the preceding Observations, see Plates II. to IX., viz. :—

Plate II.	Map of the Scottish Meteorological Stations referred to.	
Plate III.	Observations at	Edinburgh.
	Do	Wanlockhead.
	Do.	North Esk Reservoir.
	Do.	Braemar.
Plate IV.	Do.	Douglas Castle.
	Do.	Stobo Castle.
	Do.	Marchmont, Berwick.
	Do.	New Pitsligo
Plate V.	Do.	Stronvar.
	Do.	Moffat.
	Do.	Haddington.
	Do.	Greenock.
Plate VI.	Do.	Cupar (Fife).
	Do.	Dalkeith.
	Do.	Callton-Mor.
	Do.	Smeaton.
Plate VII.	Do.	Balloch Castle.
	Do.	East Linton.
	Do.	Paisley.
	Do.	Eallabus.
Plate VIII.	Do.	Glasgow, No. 1.
	Do.	Glasgow, No. 2.
	Do.	Aberdeen, No. 1.
	Do.	Aberdeen, No. 2.
Plate IX.	Do.	(Greenwich, Royal Observatory, London, communicated.)
	Do.	Gordon Castle.
	Do.	Inverness.

[APPENDIX III.

APPENDIX III.

I. Numerical Tables of Hourly Observations of Temperature, Depression of Wet-bulb, and Hygrometrical Deductions for

Aberdeen,
Glasgow, and
Greenwich.

II. Plates X. to XIV. of Graphical Projections of the preceding Hourly Observations, viz. :—

Plate X. Temperature Curve at Aberdeen.
Do. Glasgow.
Do. Greenwich.

Plate XI. Depression of Wet-bulb Therm. at Aberdeen.
Do. do. Glasgow.
Do. do. Greenwich.

Plate XII. Weight of Vapour in 1 cubic foot of Air at Aberdeen.
Do. do. Glasgow.
Do. do. Greenwich.

Plate XIII. Vapour required to saturate 1 cubic foot of air at Aberdeen.
Do. do. Glasgow.
Do. do. Greenwich.

Plate XIV. Humidity Curve at Aberdeen.
Do. Glasgow.
Do. Greenwich.

APPENDIX III.

Hourly Observations and Graphical Projections of Temperature, Depression of Wet-Bulb, and Hygrometrical Deductions for Aberdeen, Glasgow, and Greenwich.

ABERDEEN, METEOROLOGICAL COUNCIL'S OBSERVATORY.

Hour,	April 6.						April 7.						April 8.						April 9.						April 10.					
	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of Air.	Humidity; Sat. =100	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of Air.	Humidity; Sat. =100	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of Air.	Humidity; Sat. =100	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of Air.	Humidity; Sat. =100	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of Air.	Humidity; Sat. =100
	°	°	°	grs.	grs.		°	°	°	grs.	grs.		°	°	°	grs.	grs.		°	°	°	grs.	grs.		°	°	°	grs.	grs.	
1 A.M.	42·6	40·9	1·7	2·72	0·44	87	40·1	38·2	1·9	2·43	0·48	85	31·7	31·1	0·6	2·00	0·10	92	39·2	37·3	1·9	2·34	0·48	85	36·0	35·3	0·7	2·29	0·21	94
2 ,,	42·4	40·7	1·7	2·70	0·44	87	39·3	37·6	1·7	2·39	0·44	86	31·0	30·3	0·7	1·85	0·25	88	39·1	37·2	1·9	2·33	0·48	85	35·0	34·4	0·6	2·20	0·20	94
3 ,,	42·5	41·2	1·3	2·81	0·34	90	38·6	37·1	1·5	2·37	0·39	88	30·0	28·9	1·1	1·65	0·35	82	38·7	37·0	1·7	2·33	0·44	86	35·4	34·7	0·7	2·22	0·22	93
4 ,,	42·5	41·1	1·4	2·78	0·37	89	39·1	37·4	1·7	2·37	0·44	86	28·4	27·5	0·9	1·57	0·27	83	38·4	36·8	1·6	2·32	0·42	87	35·7	35·2	0·5	2·32	0·15	95
5 ,,	42·6	41·3	1·3	2·83	0·33	90	38·7	37·2	1·5	2·39	0·38	88	29·1	28·5	0·6	1·73	0·18	90	38·4	36·8	1·6	2·32	0·42	87	32·3	32·1	0·2	2·06	0·07	98
6 ,,	42·7	41·0	1·7	2·73	0·44	86	37·3	36·1	1·2	2·30	0·33	90	30·7	29·4	1·3	1·66	0·41	81	38·3	36·7	1·6	2·31	0·42	87	30·1	30·0	0·1	1·98	0·03	98
7 ,,	42·9	41·0	1·9	2·71	0·48	85	38·7	37·1	1·6	2·36	0·41	87	32·0	31·0	1·0	1·90	0·20	87	38·7	37·2	1·5	2·39	0·38	88	32·3	32·0	0·3	2·04	0·09	97
8 ,,	43·1	41·2	1·9	2·73	0·48	85	41·5	39·4	2·1	2·53	0·52	84	35·0	32·3	2·7	1·80	0·60	74	39·1	37·4	1·7	2·37	0·44	86	36·3	35·8	0·5	2·41	0·12	96
9 ,,	43·6	41·7	1·9	2·78	0·48	85	43·2	40·4	2·8	2·56	0·66	79	40·2	33·6	6·6	1·54	1·38	54	39·7	37·7	2·0	2·37	0·50	84	37·7	36·7	1·0	2·44	0·23	72
10 ,,	44·0	41·9	2·1	2·78	0·52	83	43·4	40·5	2·9	2·56	0·68	78	43·2	38·4	4·8	2·16	1·06	66	39·7	37·7	2·0	2·37	0·50	84	38·9	37·4	1·5	2·43	0·36	88
11 ,,	44·4	42·4	2·0	2·84	0·50	85	44·5	41·5	3·0	2·65	0·70	78	44·0	41·5	2·5	2·70	0·60	80	40·3	38·1	2·2	2·39	0·54	83	40·8	38·4	2·4	2·40	0·58	82
Noon.	44·4	41·7	2·7	2·70	0·64	80	44·1	41·4	2·7	2·67	0·64	79	44·9	41·7	3·2	2·65	0·74	76	41·0	38·6	2·4	2·42	0·58	81	41·2	38·1	3·1	2·30	0·72	77
Means A.M.	43·1	41·3	1·8	2·76	0·46	86	40·7	38·7	2·0	2·46	0·51	84	35·0	32·8	2·2	1·93	0·51	79	39·2	37·4	1·8	2·36	0·47	85	36·0	35·0	1·0	2·26	0·25	92
1 P.M.	44·4	41·6	2·8	2·68	0·66	79	44·0	41·4	2·6	2·68	0·62	80	45·0	42·6	2·4	2·82	0·58	82	41·3	38·6	2·7	2·39	0·64	80	40·7	37·9	2·8	2·31	0·66	79
2 ,,	44·4	41·5	2·9	2·66	0·68	78	44·9	42·3	2·6	2·77	0·62	81	45·1	43·1	2·0	2·91	0·51	85	41·5	38·7	2·8	2·39	0·66	79	41·4	38·3	3·1	2·32	0·72	77
3 ,,	44·0	41·3	2·7	2·66	0·64	79	45·1	42·6	2·5	2·81	0·61	82	45·0	42·9	2·1	2·88	0·52	84	41·7	38·8	2·9	2·39	0·68	79	41·6	37·8	3·8	2·20	0·86	73
4 ,,	43·6	40·7	2·9	2·58	0·68	78	44·7	42·6	2·1	2·85	0·52	85	44·9	42·6	2·3	2·83	0·56	83	42·4	39·4	3·0	2·44	0·70	78	42·4	38·0	4·4	2·16	0·98	70
5 ,,	43·6	41·0	2·6	2·64	0·62	80	44·4	42·7	1·7	2·90	0·44	87	44·0	42·0	2·0	2·80	0·50	84	42·0	39·3	2·7	2·46	0·64	80	42·0	37·7	4·3	2·14	0·96	70
6 ,,	43·0	40·2	2·8	2·54	0·66	79	44·2	42·1	2·1	2·80	0·52	84	42·8	40·8	2·0	2·68	0·50	85	41·8	39·1	2·7	2·44	0·64	80	41·9	38·0	3·9	2·21	0·88	72
7 ,,	42·9	40·2	2·7	2·55	0·64	80	42·6	41·0	1·6	2·74	0·42	87	41·8	40·0	1·8	2·62	0·46	86	40·2	38·2	2·0	2·42	0·50	84	41·3	37·7	3·6	2·21	0·82	73
8 ,,	42·0	39·9	2·1	2·58	0·52	84	41·4	40·4	1·0	2·78	0·26	92	41·2	39·3	1·9	2·54	0·48	85	39·0	37·5	1·5	2·40	0·40	88	41·3	37·8	3·5	2·23	0·80	74
9 ,,	41·6	39·4	2·2	2·52	0·54	84	39·5	38·6	0·9	2·63	0·22	93	40·7	38·9	1·8	2·51	0·46	86	38·9	37·4	1·5	2·43	0·36	88	41·1	38·2	2·9	2·33	0·68	78
10 ,,	41·0	39·0	2·0	2·50	0·50	84	37·0	36·5	0·5	2·45	0·15	96	40·4	38·4	2·0	2·44	0·50	84	37·6	36·3	1·3	2·33	0·33	89	40·6	37·6	3·0	2·26	0·70	77
11 ,,	40·1	38·3	1·8	2·45	0·46	86	34·9	34·3	0·6	2·18	0·21	94	40·3	38·3	2·0	2·43	0·50	84	37·0	35·9	1·1	2·28	0·32	90	40·7	37·4	3·3	2·21	0·76	75
Midnight.	39·0	37·4	1·6	2·38	0·42	87	34·6	34·1	0·5	2·20	0·16	95	39·9	37·9	2·0	2·39	0·50	84	36·3	35·3	1·0	2·26	0·27	91	40·0	37·4	2·6	2·28	0·62	79
Means P.M.	42·5	40·0	2·4	2·56	0·58	82	41·4	39·9	1·5	2·65	0·39	88	42·6	40·6	2·0	2·65	0·51	84	40·0	37·9	2·1	2·39	0·51	84	41·2	37·8	3·4	2·24	0·79	75
Means 24h	42·8	40·7	2·1	2·66	0·52	84	41·0	39·3	1·7	2·56	0·45	86	38·8	46·7	2·1	2·29	0·51	82	39·6	37 6	2·0	2·38	0·49	84	38·6	36·4	2·2	2·25	0·52	84

GLASGOW, METEOROLOGICAL COUNCIL'S OBSERVATORY.

Hour.	April 6,						April 7.						April 8.						April 9.						April 10.					
	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of Air.	Humidity; Sat. =100	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of Air.	Humidity; Sat. =100	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of Air.	Humidity; Sat. =100	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of Air.	Humidity; Sat. =100	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of Air.	Humidity; Sat. =100
	°	°	°	grs.			°	°	°	grs.			°	°	°	grs.			°	°	°	grs.			°	°	°	grs.		
1 A.M.	42·1	40·0	2·1	2·59	0·52	84	41·8	39·6	2·2	2·54	0·54	84	38·6	37·2	1·4	2·40	0·36	89	38·3	36·9	1·4	2·35	0·38	88	37·8	37·0	0·8	2·52	0·16	93
2 ,,	42·2	40·4	1·8	2·66	0·46	86	41·5	39·3	2·2	2·51	0·54	83	37·0	36·1	0·9	2·33	0·27	92	37·7	36·1	1·6	2·26	0·41	86	36·5	36·0	0·5	2·45	0·10	96
3 ,,	42·3	41·0	1·3	2·77	0·36	90	41·4	39·1	2·3	2·48	0·56	82	37·0	36·0	1·0	2·30	0·30	91	36·4	35·0	1·4	2·16	0·38	88	35·4	35·0	0·4	2·32	0·12	96
4 ,,	42·7	41·2	1·5	2·79	0·38	88	40·3	38·5	1·8	2·47	0·46	86	36·5	36·0	0·5	2·45	0·10	96	35·8	34·5	1·3	2·09	0·39	88	34·2	33·8	0·4	2·26	0·06	96
5 ,,	43·0	41·8	1·2	2·86	0·34	90	39·1	37·3	1·8	2·35	0·46	86	36·4	35·8	0·6	2·40	0·14	95	36·2	35·0	1·2	2·18	0·34	89	33·4	33·0	0·4	2·12	0·12	96
6 ,,	43·0	41·8	1·2	2·86	0·34	90	39·0	37·0	2·0	2·30	0·50	84	36·0	35·4	0·6	2·32	0·18	95	36·5	35·0	1·5	2·15	0·40	87	31·7	31·3	0·4	2·08	0·02	95
7 ,,	43·4	42·0	1·4	2·86	0·38	89	40·0	37·6	2·4	2·32	0·58	81	36·8	36·0	0·8	2·42	0·16	93	36·1	34·4	1·7	2·07	0·44	85	32·1	32·0	0·1	2·08	0·03	99
8 ,,	44·0	42·2	1·8	2·84	0·46	86	41·5	38·9	2·6	2·43	0·62	81	39·4	37·9	1·5	2·44	0·40	88	38·1	36·0	2·1	2·19	0·52	82	33·0	32·8	0·2	2·20	0·00	97
9 ,,	45·0	42·8	2·2	2·86	0·54	84	43·4	40·4	3·0	2·54	0·70	78	42·8	40·0	2·8	2·52	0·66	79	39·2	36·8	2·4	2·24	0·58	81	33·0	33·0	0·0	2·20	0·00	100
10 ,,	45·0	43·0	2·0	2·90	0·50	85	45·2	41·9	3·3	2·60	0·78	76	46·3	40·0	6·3	2·17	1·46	60	40·2	37·6	2·6	2·30	0·62	80	36·5	35·6	0·9	2·33	0·22	92
11 ,,	46·5	44·2	2·3	3·04	0·61	84	47·0	43·2	3·8	2·74	0·96	74	49·4	42·8	6·6	2·42	1·62	59	42·4	39·0	3·4	2·36	0·78	75	39·9	38·7	1·2	2·62	0·27	90
Noon.	47·5	44·3	3·2	2·94	0·81	78	49·3	44·7	4·6	2·81	1·22	70	52·0	42·9	9·1	2·18	2·22	50	45·2	40·8	4·4	2·44	1·00	70	41·4	40·0	1·4	2·66	0·38	89
Means A.M.	43·9	42·1	1·8	2·83	0·48	86	42·5	39·8	2·7	2·51	0·66	80	40·7	38·0	2·7	2·36	0·66	82	38·5	36·4	2·1	2·23	0·52	83	35·4	34·8	0·6	2·32	0·12	95
1 P.M.	48·0	44·5	3·5	2·90	0·90	76	51·0	45·4	5·6	2·78	1·42	65	54·0	44·1	9·9	2·22	2·48	47	47·8	42·7	5·1	2·56	1·22	67	44·2	42·1	2·1	2·80	0·52	84
2 ,,	48·6	44·6	4·0	2·86	1·06	73	52·0	46·2	5·8	2·84	1·56	65	55·0	44·1	10·9	2·12	2·78	44	49·8	44·0	5·8	2·62	1·46	63	46·0	42·8	3·2	2·76	0·84	78
3 ,,	49·3	45·1	4·2	2·89	1·14	72	53·0	47·3	5·7	2·96	1·54	65	56·0	44·3	11·7	2·16	2·84	42	51·9	45·0	6·9	2·61	1·77	59	47·9	43·3	4·6	2·67	1·12	70
4 ,,	49·0	44·6	4·4	2·82	1·18	71	52·8	46·8	6·0	2·88	1·60	65	56·1	44·0	12·1	2·09	2·93	41	53·1	46·0	7·1	2·69	1·83	59	48·2	43·0	5·2	2·58	1·26	66
5 ,,	48·1	43·3	4·8	2·65	1·17	68	52·2	46·0	6·2	2·78	1·64	63	56·0	43·2	12·8	1·94	3·06	39	54·1	47·0	7·1	2·79	1·93	59	48·4	43·8	4·6	2·72	1·16	70
6 ,,	46·7	42·1	4·6	2·55	1·12	69	49·2	44·2	5·0	2·72	1·30	67	53·0	42·5	10·5	2·05	2·45	45	52·3	46·4	5·9	2·85	1·58	65	46·6	42·7	3·9	2·68	0·98	74
7 ,,	43·7	40·2	3·5	2·47	0·80	74	45·7	41·6	4·1	2·55	0·99	72	48·3	43·0	5·3	2·57	1·29	66	49·0	45·0	4·0	2·90	1·10	73	43·2	40·0	3·2	2·48	0·74	77
8 ,,	41·6	39·0	2·6	2·44	0·62	80	43·8	40·8	3·0	2·58	0·70	77	44·5	40·3	4·2	2·41	0·94	70	45·5	42·0	3·5	2·65	0·85	75	41·0	38·3	2·7	2·36	0·64	79
9 ,,	42·9	39·9	3·0	2·49	0·70	78	42·0	39·3	2·7	2·46	0·64	80	41·8	39·8	2·0	2·58	0·50	86	42·7	40·1	2·6	2·55	0·62	81	40·0	37·6	2·4	2·32	0·58	81
10 ,,	42·5	39·9	2·6	2·53	0·62	81	40·8	38·7	2·1	2·46	0·52	84	40·0	38·9	1·1	2·58	0·32	91	40·8	39·0	1·8	2·52	0·46	86	40·1	37·8	2·3	2·35	0·56	82
11 ,,	42·3	39·9	2·4	2·55	0·58	82	40·6	38·0	2·6	2·34	0·62	80	39·3	38·1	1·2	2·50	0·33	90	38·5	37·3	1·2	2·44	0·31	90	40·2	37·8	2·4	2·34	0·58	81
Midnight.	42·2	39·7	2·5	2·52	0·60	82	39·5	37·1	2·4	2·27	0·58	81	38·9	37·6	1·3	2·49	0·30	90	38·1	37·1	1·0	2·42	0·29	91	40·2	37·9	2·3	2·36	0·56	82
Means P.M.	45·4	41·9	3·5	2·64	0·87	76	46·9	42·6	4·3	2·64	1·09	72	48·6	41·7	6·9	2·31	1·68	63	47·0	42·6	4·3	2·63	1·12	72	43·8	40·6	3·2	2·54	0·80	77
Means 24h	44·6	42·0	2·6	2·74	0·68	81	44·7	41·2	3·5	2·58	0·88	76	44·6	39·8	4·8	2·34	1·17	72	42·8	39·5	3·3	2·43	0·82	78	39·6	37·7	1·9	2·43	0·46	86

ROYAL OBSERVATORY, GREENWICH, FROM PHOTO RECORDS OF 1882.

Hour.	April 6.						April 7.						April 8.						April 9.						April 10.					
	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of Air.	Humidity; Sat. =100	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of Air.	Humidity; Sat. =100	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of Air.	Humidity; Sat. =100	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of air.	Humidity; Sat. =100	Dry Bulb.	Wet Bulb.	Depression of Wet.	Weight of Vapour in 1 cub. ft. of Air.	Vapour required to saturate 1 cub. ft. of air.	Humidity; Sat. =100
	°	°	°	grs.			°	°	°	grs.			°	°	°	grs.			°	°	°	grs.			°	°	°	grs.		
1 A.M.	41·5	40·2	1·3	2·71	0·34	90	40·9	39·5	1·4	2·66	0·33	89	41·8	40·6	1·2	2·80	0·28	91	38·0	36·9	1·1	2·38	0·32	90	38·3	37·3	1·0	2·46	0·27	92
2 ,,	40·5	39·4	1·1	2·67	0·28	91	41·0	39·5	1·5	2·60	0·40	88	42·4	41·2	1·2	2·82	0·32	90	37·1	36·6	0·5	2·47	0·14	96	38·0	37·0	1·0	2·40	0·30	91
3 ,,	40·2	39·4	0·8	2·70	0·22	94	40·1	38·8	1·3	2·55	0·36	90	40·5	39·5	1·0	2·70	0·25	92	36·9	36·2	0·7	2·47	0·12	94	37·8	36·9	0·9	2·49	0·19	93
4 ,,	40·4	39·8	0·6	2·80	0·14	95	38·9	38·0	0·9	2·61	0·18	93	40·0	39·3	0·7	2·69	0·21	94	38·5	37·8	0·7	2·59	0·16	95	38·2	37·2	1·0	2·44	0·28	91
5 ,,	41·2	40·7	0·5	2·89	0·13	96	38·2	37·4	0·8	2·50	0·22	93	39·1	38·4	0·7	2·61	0·20	94	39·7	38·6	1·1	2·61	0·26	91	36·7	35·9	0·8	2·40	0·17	94
6 ,,	41·4	41·0	0·4	2·96	0·08	97	38·6	37·9	0·7	2·61	0·15	95	39·4	38·8	0·6	2·70	0·14	95	41·1	40·0	1·1	2·69	0·32	91	36·6	36·0	0·6	2·44	0·12	95
7 ,,	42·5	42·0	0·5	3·05	0·10	96	43·0	41·2	1·8	2·74	0·46	86	41·5	40·4	1·1	2·77	0·28	92	42·0	40·9	1·1	2·78	0·32	91	38·6	38·0	0·6	2·64	0·12	95
8 ,,	44·1	43·8	0·3	3·23	0·08	98	48·0	44·9	3·1	2·98	0·82	78	47·9	45·5	2·4	3·12	0·67	84	42·7	41·5	1·2	2·88	0·29	90	42·6	40·8	1·8	2·70	0·46	86
9 ,,	48·4	46·3	2·1	3·28	0·56	85	51·0	47·4	3·6	3·22	0·98	76	53·0	49·2	3·8	3·44	1·06	73	48·3	45·1	3·2	3·00	0·86	78	46·9	44·3	2·6	2·98	0·71	82
10 ,,	53·7	49·9	3·8	3·51	1·13	76	53·7	48·7	5·0	3·24	1·40	69	57·3	51·2	6·1	3·43	1·83	65	53·0	48·6	4·4	3·28	1·22	72	48·1	44·3	3·8	2·85	0·97	74
11 ,,	56·9	52·6	4·3	3·89	1·29	74	55·4	49·3	6·1	3·15	1·79	65	58·4	51·2	7·2	3·32	2·16	60	55·4	49·4	6·0	3·18	1·76	65	49·1	44·9	4·2	2·87	1·14	72
Noon.	60·7	53·9	6·8	3·71	2·23	63	57·2	49·7	7·5	3·12	2·12	59	59·6	52·1	7·5	3·46	2·26	59	57·1	51·1	6·0	3·42	1·80	65	51·8	46·5	5·	2·92	1·44	67
Means A.M.	46·0	44·1	1·9	3·12	0·55	88	45·5	42·7	2·8	2·83	0·77	82	46·7	43·9	2·8	2·99	0·80	82	44·2	41·9	2·3	2·81	0·63	85	41·9	39·9	2·0	2·62	0·51	86
1 P.M.	62·2	54·7	7·5	3·79	2·45	60	57·5	50·0	7·5	3·15	2·15	59	59·3	51·5	7·8	3·32	2·34	58	58·8	52·2	6·6	3·56	2·00	64	51·5	46·4	5·1	2·93	1·37	68
2 ,,	61·0	53·5	7·5	3·60	2·40	60	57·3	50·3	7·0	3·23	2·03	61	59·0	51·1	7·9	3·23	2·37	57	57·1	51·3	5·8	3·46	1·74	66	50·9	46·2	4·7	2·97	1·22	71
3 ,,	59·5	51·9	7·6	3·42	2·28	59	57·1	50·2	6·9	3·23	1·99	61	57·9	52·0	5·9	3·61	1·77	66	54·6	49·7	4·9	3·38	1·44	70	51·0	46·2	4·8	2·94	1·26	69
4 ,,	57·0	50·3	6·7	3·26	1·94	62	55·0	49·3	5·7	3·19	1·71	66	57·8	50·8	7·0	3·28	2·08	61	52·8	48·5	4·3	3·32	1·24	73	50·8	45·9	4·9	2·90	1·28	69
5 ,,	53·8	49·2	4·6	3·36	1·30	71	53·3	47·7	5·6	3·01	1·55	66	55·3	48·5	6·8	2·97	1·96	61	51·4	46·9	4·5	3·04	1·24	71	49·8	45·0	4·8	2·82	1·26	69
6 ,,	51·5	46·9	4·6	3·03	1·27	71	51·2	46·5	4·7	2·98	1·26	70	51·7	46·6	5·1	2·95	1·39	68	48·3	45·1	3·2	3·00	0·86	78	48·8	44·4	4·4	2·80	1·16	71
7 ,,	48·2	44·7	3·5	2·92	0·92	76	48·7	44·7	4·0	2·87	1·07	73	48·7	44·9	3·8	2·91	1·03	74	44·6	42·7	1·9	2·88	0·48	86	46·4	42·8	3·6	2·72	0·92	75
8 ,,	46·1	43·5	2·6	2·94	0·67	82	46·7	43·6	3·1	2·91	0·76	79	46·7	43·5	3·2	2·88	0·79	78	42·7	40·9	1·8	2·71	0·46	86	44·6	42·0	2·6	2·74	0·62	80
9 ,,	44·3	42·0	2·3	2·77	0·56	82	45·7	43·0	2·7	2·83	0·71	81	44·9	42·2	2·7	2·75	0·64	80	41·0	39·4	1·6	2·58	0·42	87	43·8	41·2	2·6	2·66	0·62	80
10 ,,	43·1	40·9	2·2	2·67	0·54	83	45·1	43·0	2·1	2·89	0·53	84	43·3	40·5	2·8	2·57	0·66	79	40·8	38·9	1·4	2·55	0·38	89	43·5	41·0	2·5	2·65	0·60	80
11 ,,	42·1	40·1	2·0	2·60	0·50	85	44·2	42·5	1·7	2·88	0·44	87	40·8	39·0	1·8	2·52	0·46	86	39·7	38·2	1·5	2·49	0·38	88	42·7	40·5	2·2	2·63	0·54	84
Midnight.	41·7	40·0	1·7	2·63	0·44	87	43·7	42·2	1·5	2·89	0·38	88	39·1	37·5	1·6	2·39	0·38	87	38·4	37·3	1·1	2·45	0·29	91	(41·2)	(39·7)	1·5	2·62	0·40	88
Means P.M.	50·9	46·5	4·4	3·08	1·28	74	50·5	46·1	4·4	3·00	1·22	73	50·4	45·7	4·7	2·95	1·32	71	47·5	44·3	3·2	2·95	0·91	79	47·1	43·4	3·6	2·79	0·94	75
Means 24h	48·4	45·3	3·1	3·10	0·92	81	48·0	44·4	3·6	2·92	1·00	78	48·6	44·8	3·8	2·97	1·06	76	45·9	43·1	2·8	2·88	0·77	82	44·5	41·6	2·8	2·70	0·72	80

APPENDIX IV.

1. Greenwich Testimonies as to Cosmical Accompaniments of Aurora being deficient on April 8, 1882, and April 30, 1883.—Letters 1 and 2.

Royal Observatory, Greenwich,
London, S.E., May 12, 1883.

Dear Sir,—In regard to unusual phenomena on 1882, April 8, and 1883, April 30, as compared with adjacent days, I am requested by the Astronomer-Royal to inform you as follows:—

The magnetical regisfers (Declination, Horizontal Force, and Vertical Force) indicate nothing unusual, neither do the Meteorological (Barometer, Thermometer, Electrometer).

Wind 1882, April 6 to 10, steady E.N.E. and N.E. throughout the greater part of the five days, changing on afternoon of April 10.

Wind 1883, April 29 to May 1. Change on April 30 from N. to S.W. at 4^h, and from S.W. to E. at $6\frac{1}{2}^h$. On April 29 change in opposite direction about same times. On May 1, steady N.E. wind.

1882, April 8. Brilliantly fine and cloudless throughout, similar on April 6 and 7, very little cloud on April 9, cloudy but fine on April 10.

1883, April 30. A very similar day (in all respects) to May 1.

I am, Dear Sir,

Yours very truly,

(Signed) William Ellis.

Prof. C. P. Smyth.

Royal Observatory, Greenwich,
London, S.E., May 14, 1883.

Dear Sir,—With reference to your inquiry as to whether there was anything unusual on the Solar photographs of 1882, April 8, and on 1883, April 30, as compared with photographs taken on neighbouring days, the Astronomer-Royal requests me to say that there are no noteworthy changes in the spots shown on pictures taken on 1882, April 7, 8, and 9. Small spots were constantly forming or disappearing, but nothing unusual is shown.

The picture taken on 1883, April 30, shows a group of several very small spots which disappeared before 1883, May 1. Two small groups not visible on 1883, April 30, are shown on the picture taken on May 1. The changes are not at all unusual in character or amount.

I am, Dear Sir,

Yours very truly,

(Signed) E. Dunkin.

Prof. C. Piazzi Smyth.

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2. Of the Aurora said to have been observed at 1 Station out of 24 in Scotland on April 8, 1882.

Letter from the Gordon Castle Observer to Mr Buchan, Secretary Scottish Meteorological Society.

Dear Sir,—I am in receipt of your note inquiring about "Aurora" entered in my notes of daily readings in 1882. I have looked up the Schedule, and find there are no particulars dated; simply *Aurora*. The time is too far back to bring my memory to it, but I see by the readings *under*, that it had been the precursor of a considerable depression of the atmosphere at the period.

I am, Sir,

Yours faithfully,

(Signed) John Webster.

3. Of Auroræ Spectroscopically observed in Edinburgh at the Astronomers' House in 1882 and 1883.

The concluding remark in Mr Webster's letter, that the date of his stated Aurora, April 8, 1882, was followed by a considerable depression of the atmosphere, is perfectly true; for the record of Barometer (uncorrected), wind, rainfall, and clouds, kept at the Royal Observatory, Edinburgh, in connection with Time signalling, runs thus from April 5 to April 15, 1882 :—

Day.	Barometer.	Wind. Miles per hour.	Wind. Direction.	Rainfall, Depth of.	Clouds. 0 to 10.
April.	Inches.			Inch.	
5	29·99	3	N.E.	·000	10
6	30·10	2	N.E.	·013	6
7	30·23	4	N.E.	·000	0
8	30·22	2	N.E.	·000	0
9	30·02	2	N.E.	·000	3
10	29·77	3	N.E.	·000	0
11	29·58	2	N.N.E.	·000	10
12	29·45	3	S.S.E.	·000	9
13	29·06	8	E.	·035	10
14	28·83	10	N.E.	·424	10
15	29·29	1	N.	·230	10

That circumstance, however, does not prove that the luminosity Mr Webster observed in the sky at Gordon Castle was a real Aurora. It certainly could not have been one of the grander Auroræ, or it would have been noted at some of the 23 other stations; would have imprinted itself indelibly on the observer's memory, and would have marked itself on the continuous photographic curves of the magnetic needles at Greenwich.

Whether it was, however, a faint Aurora, or perhaps some other luminous manifestation, I do not wish to suggest a word either for or against; but if the observer could have said that he spectroscoped it with a pocket spectroscope, and saw the Auroral Citron line,—I should have accepted the testimony immediately. For I myself have never yet spectroscoped any decided Aurora, without its showing that line; and have never seen that line in any other light, though I have, on one occasion, elicited the line out of a full-Moon, mid-night sky, when at the time there was no appearance of Aurora or any of its usual accompaniments,—but where, an hour before, there had been some unmistakable needle-shaped jets and darts of its light on the Northern horizon.

The opportunities I have had for good numerical observations of the Auroral spectroscopic line, during the last 15 months have not been many; but may form a useful addendum to the present paper,—as follows :—

☉ October 22, 1882, at 11^h p.m.; the moon ten days old, and the sky bright with moonlight; Aurora seen as a faint but regularly-shaped arc on the N.W. horizon; spectrum place of its Citron line =45 511 of Wave Number per Brit. Inch.

♄ October 28, 1882, at midnight; past full-Moon; sky clear and frosty. No Aurora visible to the naked eye at the time, though there had been earlier in the evening. The place of Aurora line, doubtfully observed, came out 45 350 (?) W.N. Place.

♂ November 14, 1882. Aurora lasted through much of the night, but chiefly behind clouds.

♀ November 17, 1882. A grand Aurora; but barely seen here by reason of clouds, smoke, and direction.

♄ November 25, 1882, 11^h 30^m p.m.; Moon just past the full. No Aurora to naked eye, but its line was clearly seen in the spectroscope, followed by a broad band of continuous spectrum of the Moonlight. Place of the line observed at 45 593; while the continuous band of Moonlight began at 46 610, culminated in intensity near 48 200, and ended gradually near 52 610 W.N. Place.

☾ March 26, 1883, at 10^h p.m.; a rather bright Auroral arc northwards, its central portion rising 10° or 15° high, and having dark shade underneath. Its Citron line's place measured 45 558 W.N. Place.

♂ March 27, 1883, at 10^h p.m.; a long low quiescent, or blandly-shining faint arch of Aurora on the northern horizon. Its Citron line's spectrum place measured 45 542 W.N. Place.

This latter was the best Auroral manifestation I have seen this season. Many others I believe have been noted in Sweden and Norway; but those countries seem to be situated over one of the Earth's invisible *quasi* volcanoes, or rather perhaps "maelstroms" of Auroræ; so that as Professor ANGSTROM noted many years ago, and Professor LEMSTROM more recently, there is sometimes an Auroral phosphorescence there on everything about them, air, earth, ice, and water.

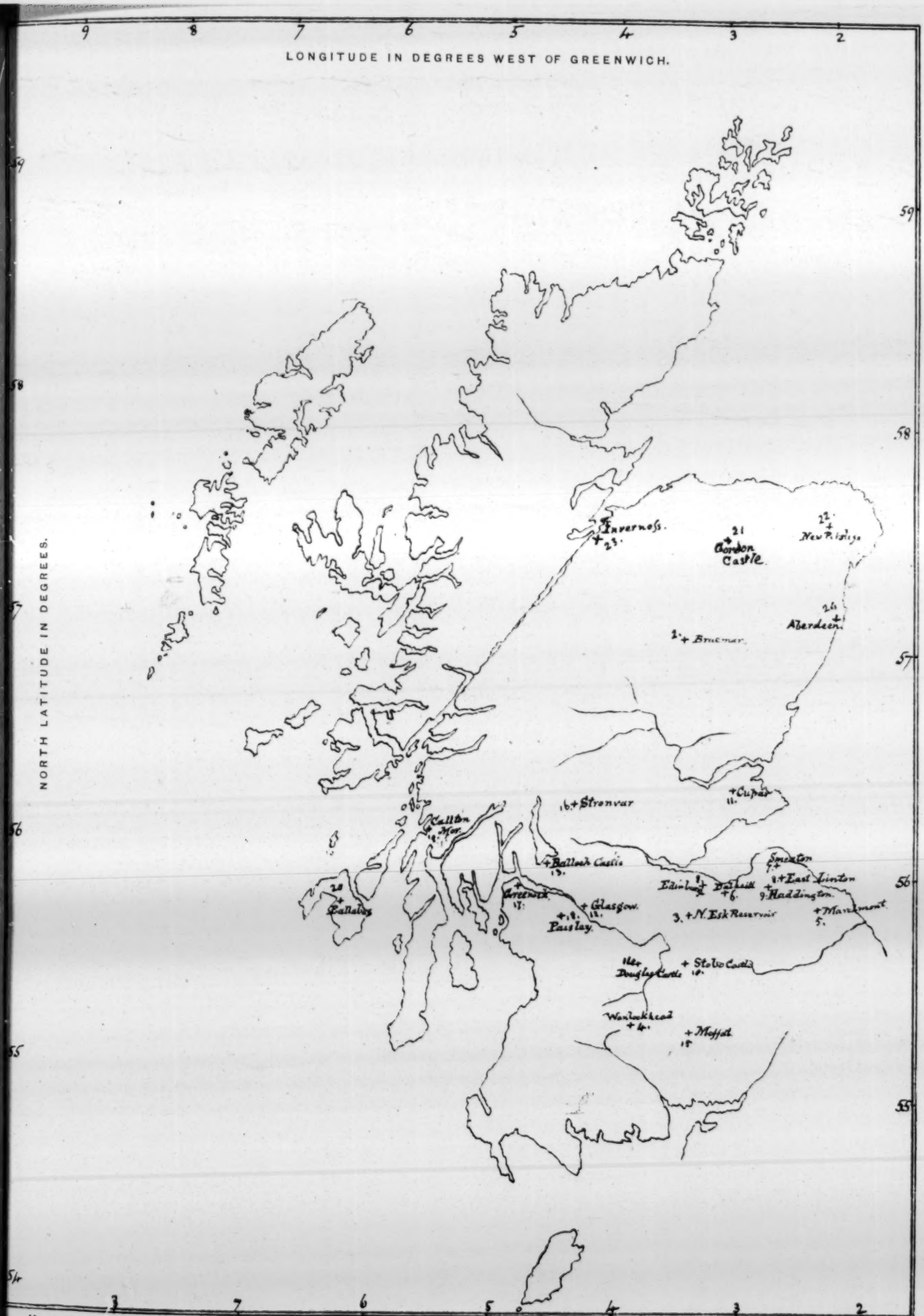
Such phosphorescence, however, as Professor LEMSTROM has well remarked, is recognised by its giving to the spectroscope the well-known Citron Aurora line, whose place is close, according to my observations, to 45 550 W.N. Place.

But other kinds of phosphorescence, so far as I have observed them, give only a band of continuous spectrum in the green and glaucous regions, necessarily more refrangible than the Aurora line; or

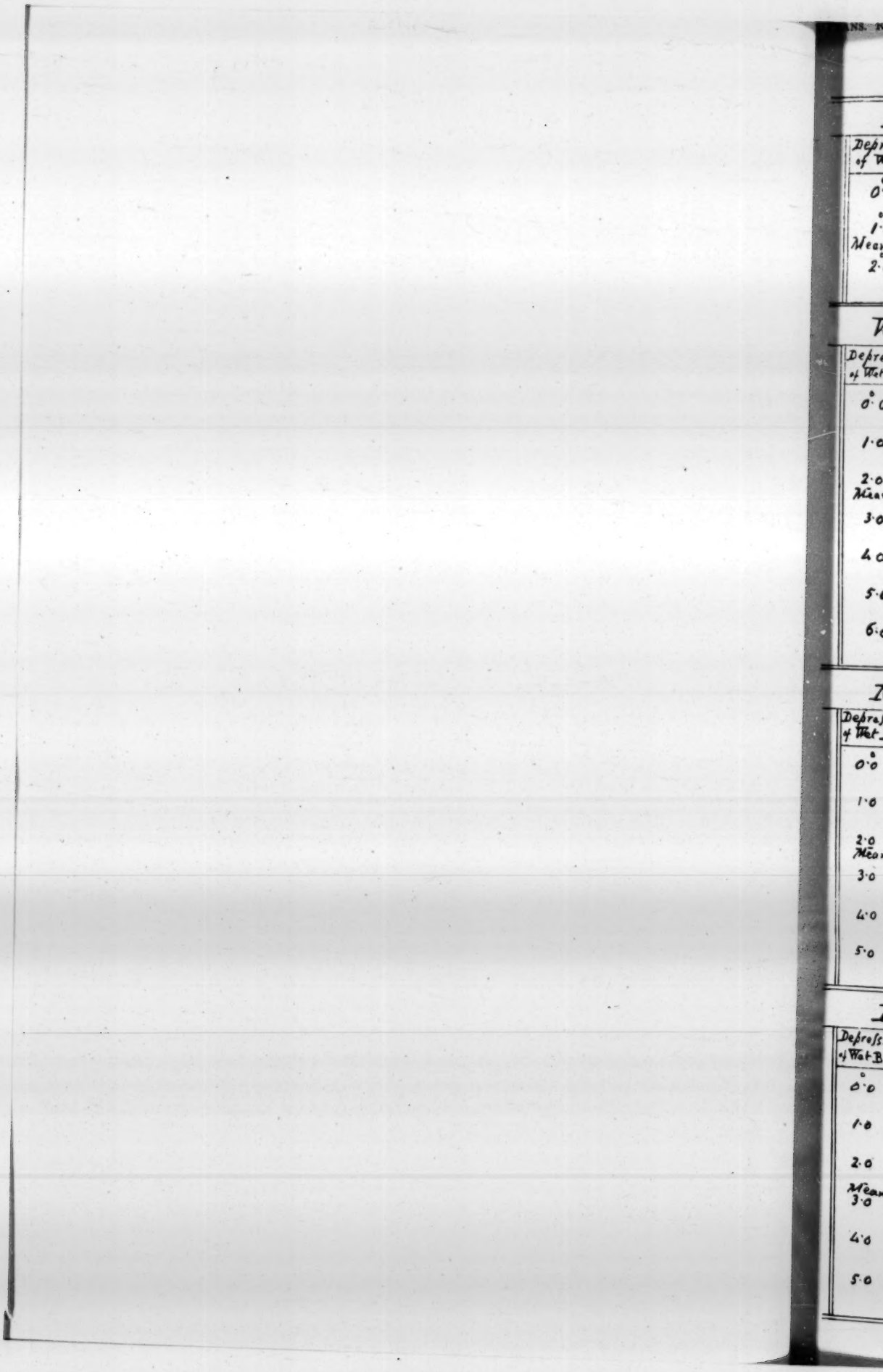
Stick phosphorus in a chamber, has the maximum brightness of its broad, faint, band at	49 000	W.N. Pl.
Animal phosphorescence at sea, has the similar centre at . .	50 300	„
Carbo-hydrogen blue flame, when too faint to show its individual lines, has its chief brightness near	49 200	„
The Zodiacal light has the same, at or near . . .	48 150	„
Twilight has the same, at or about	48 150	„
While Moon light, as above, has it at or near . . .	48 200	„

The last three therefore can hardly fail to be of one and the same Solar origination; but the two first are quite different from them; and still more different are they from the chief Auroral line, both in appearance and spectrum place; while the third suits our faintly bright night clouds of April 8, 1882, with a broad slit perfectly.

NORTH LATITUDE IN DEGREES.

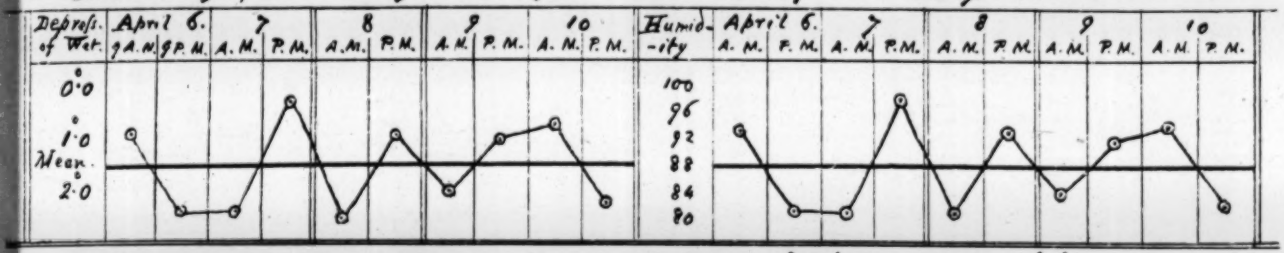


ndix II., Plate 1.-Map of the Scottish Stations, followed by seven Plates of Graphical Projections of Hygrometric Observatio

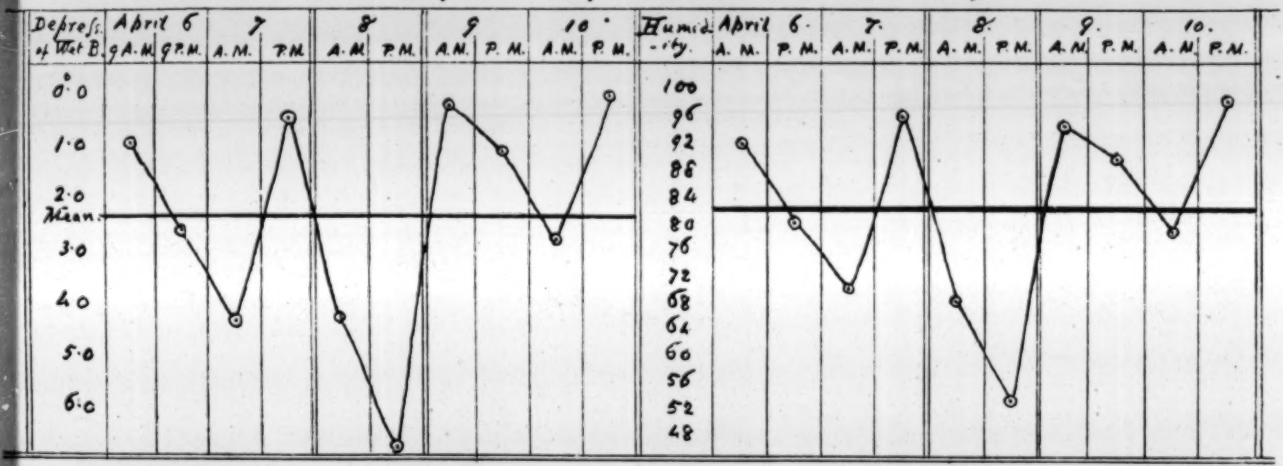


Stations here, after Edinburgh, arranged in order of height.

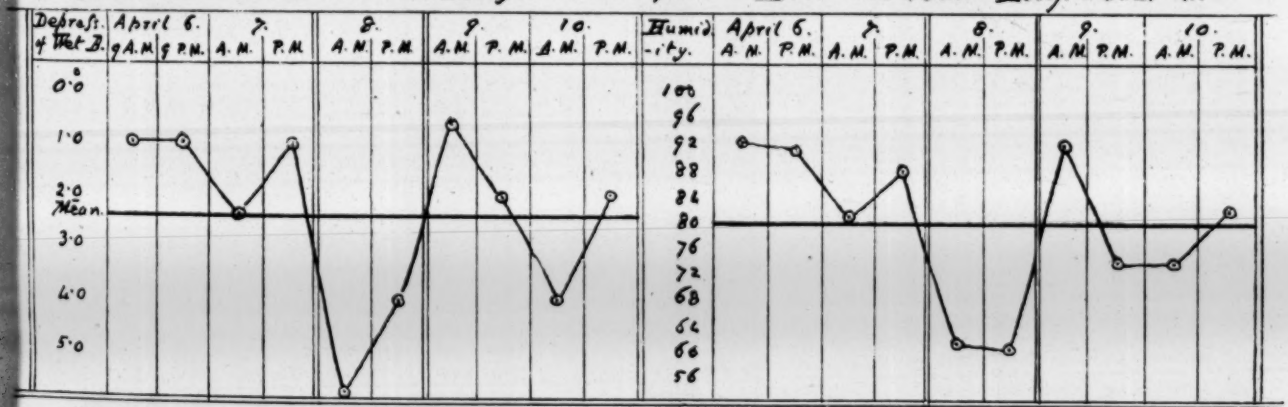
Edinburgh, No 1. Height = 162 feet. Lat. = 55°.57 N. Long. = 3°.11 W.



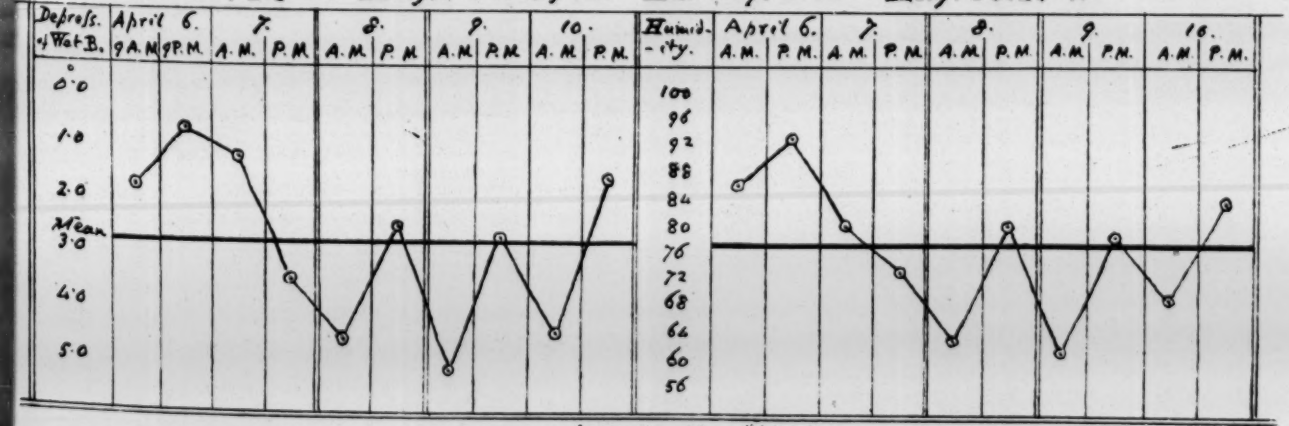
Wanlockhead. No 4. Height = 1334 feet. Lat. = 55°.24 N. Long. = 3°.48 W.



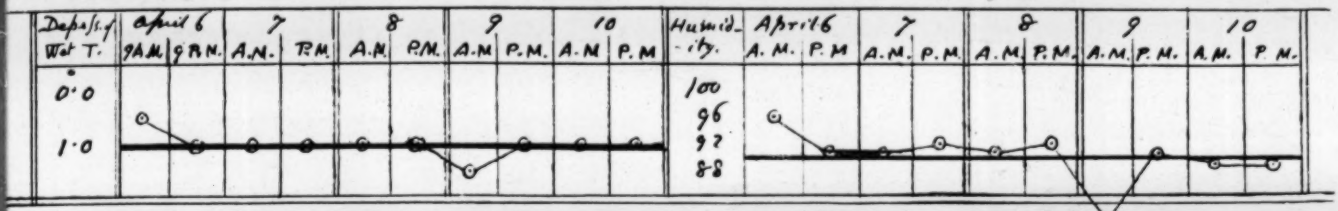
North Esk Reservoir, No 3. Height = 1150 feet. Lat. = 55°.48 N. Long. = 3°.21 W.



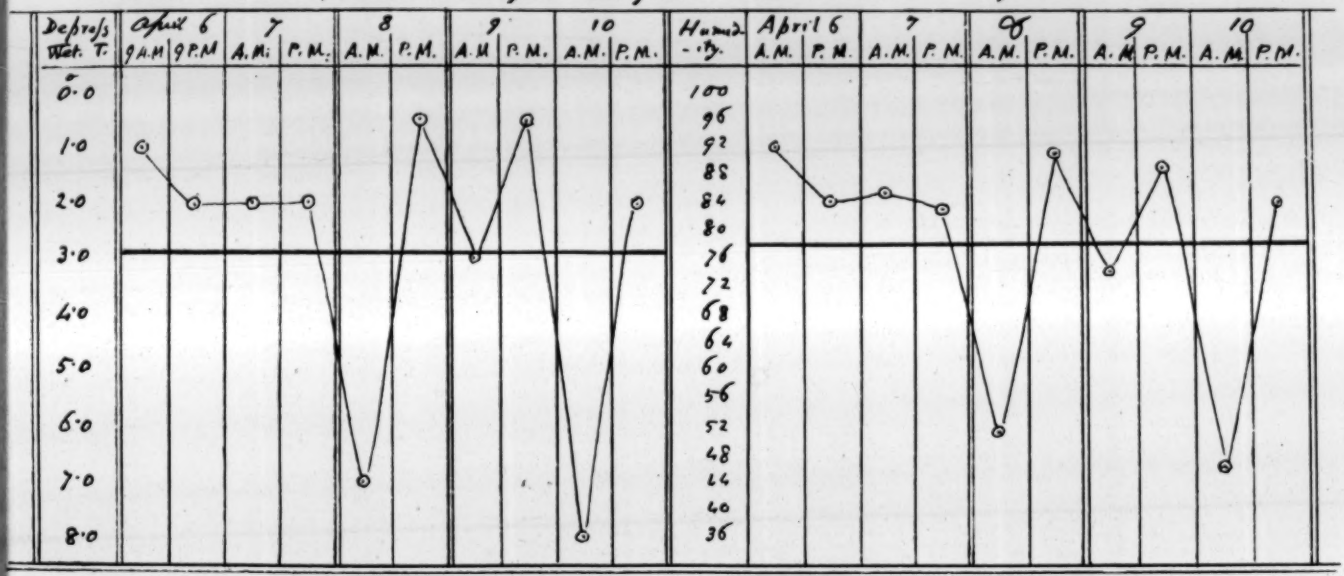
Braemar, No 2. Height = 1114 feet. Lat. = 57°.0 N. Long. = 3°.24 W.



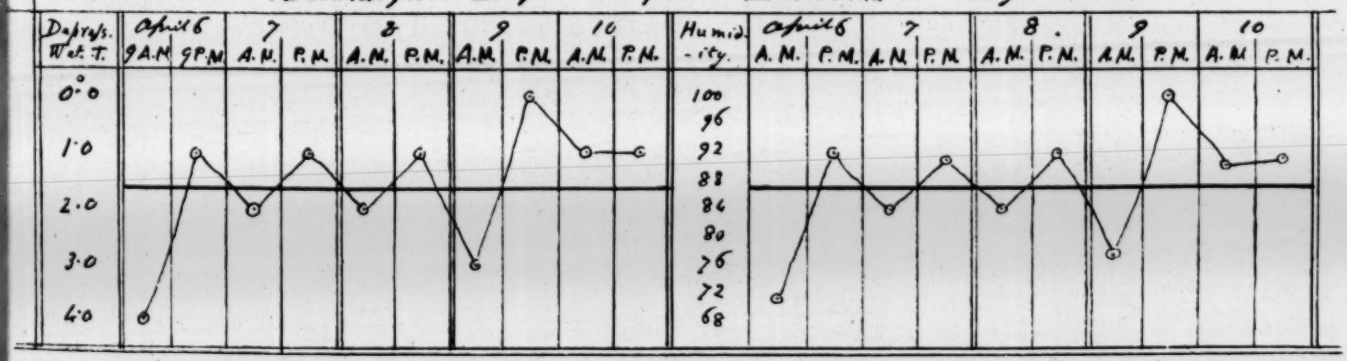
Douglas Castle. No. 14. Height = 783 feet. Lat. = 55°.35 N., Long. = 3°.52 W.



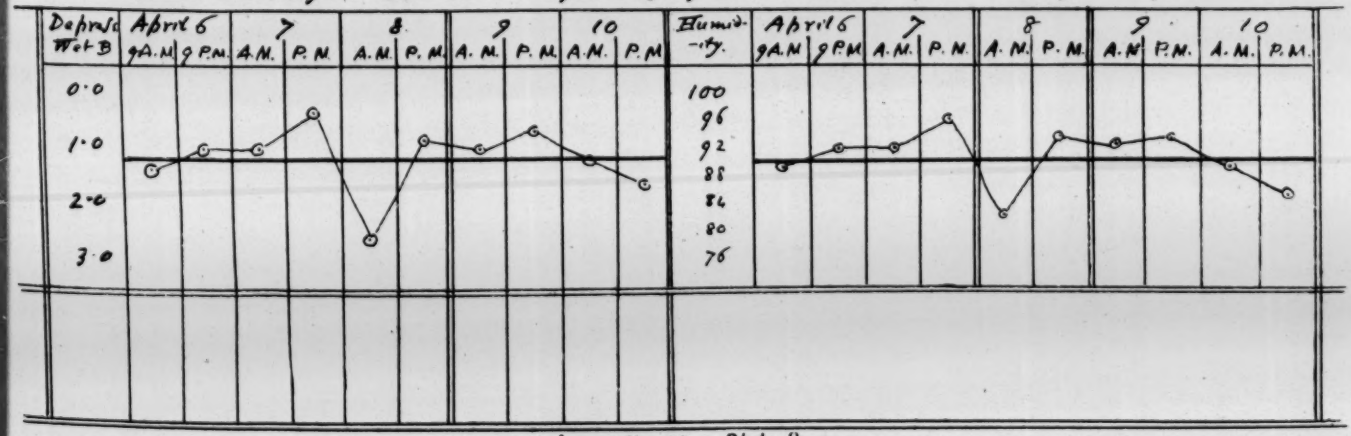
Strobo Castle, No. 10. Height = 600 feet. Lat. = 55°.35 N. Long. = 3°.25 W.



Marchmont (Berwick) No. 5. Height = 500 feet. Lat. = 55°.44 N. Long. = 2°.25 W.

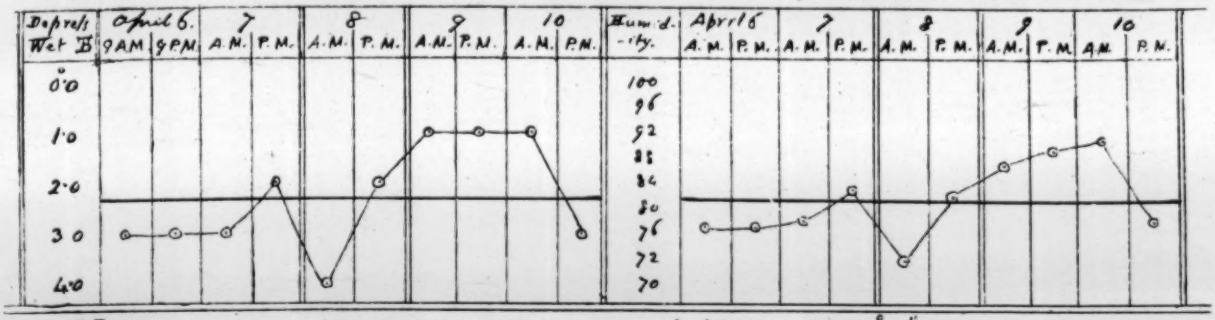


New Pitsligo. No. 22. Height = 495 feet. Lat. = 57°.35 Long. = 2°.9 W.

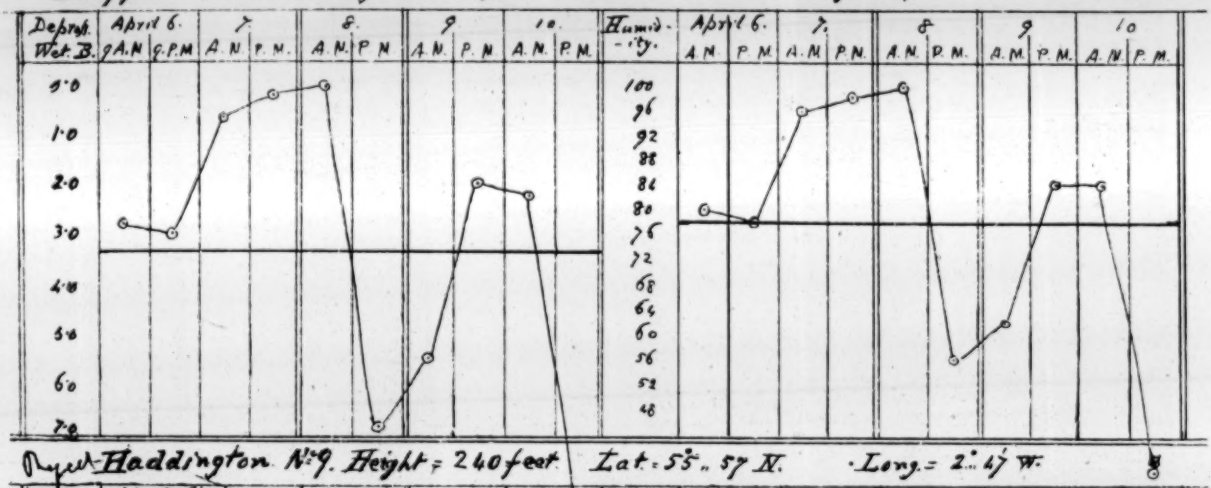


Appendix II. Plate 3.

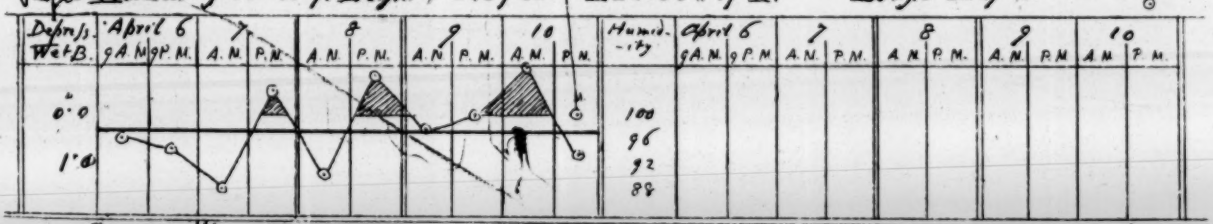
Stronvar No. 16 Height = 428 feet. Lat. = 56°.20 N. Long. = 4°.20 W.



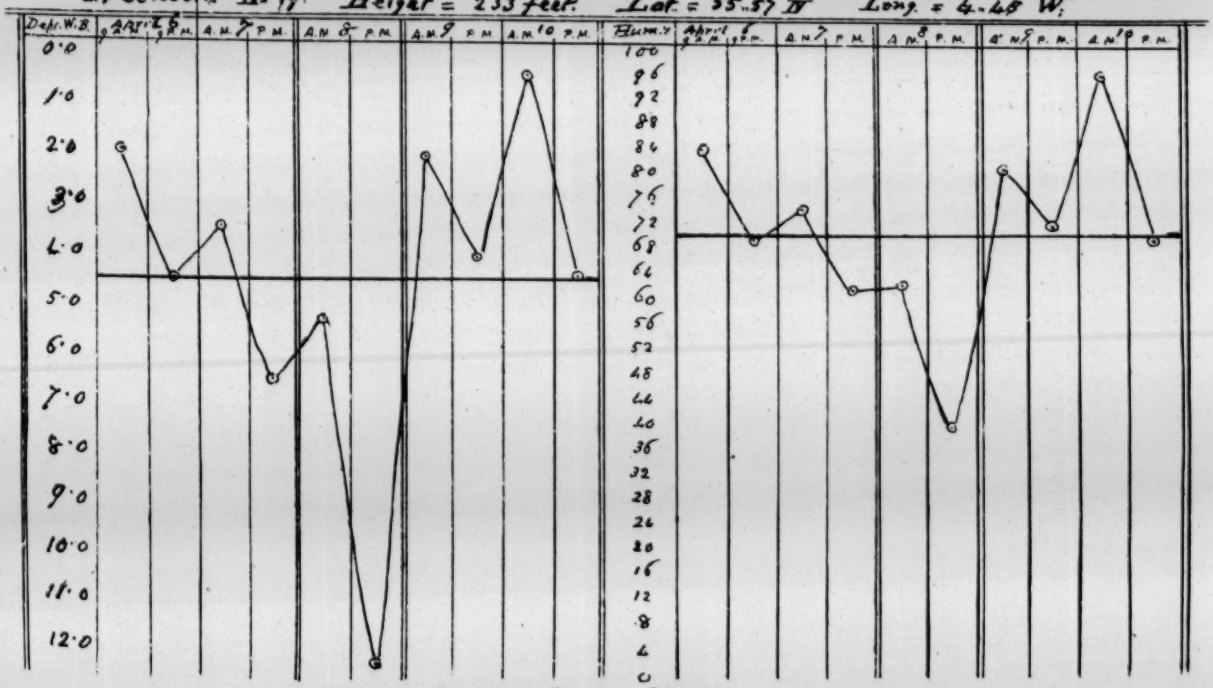
Moffat No. 15 Height = 350 feet. Lat. = 55°.21 N. Long. = 3°.27 W.



Ayr-Haddington No. 9. Height = 240 feet. Lat. = 55°.57 N. Long. = 2°.47 W.

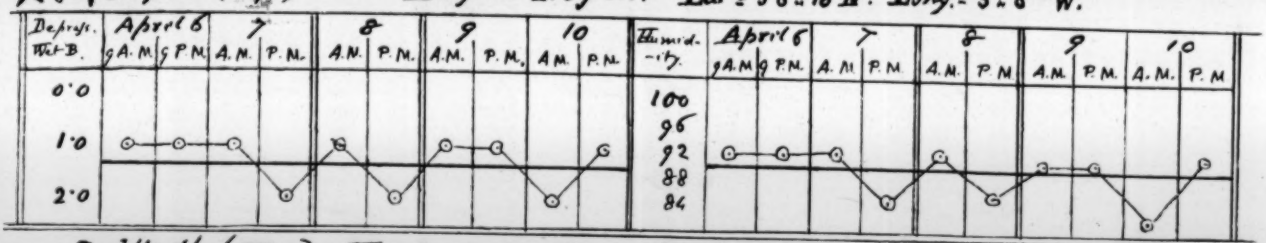


Greenock. No. 17. Height = 233 feet. Lat. = 55°.57 N Long. = 4°.48 W.

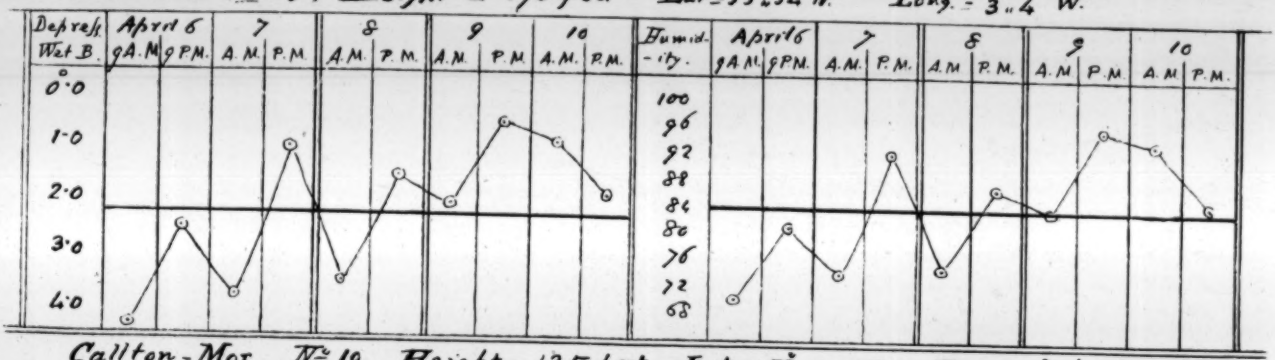


Appendix II. Plate 4.

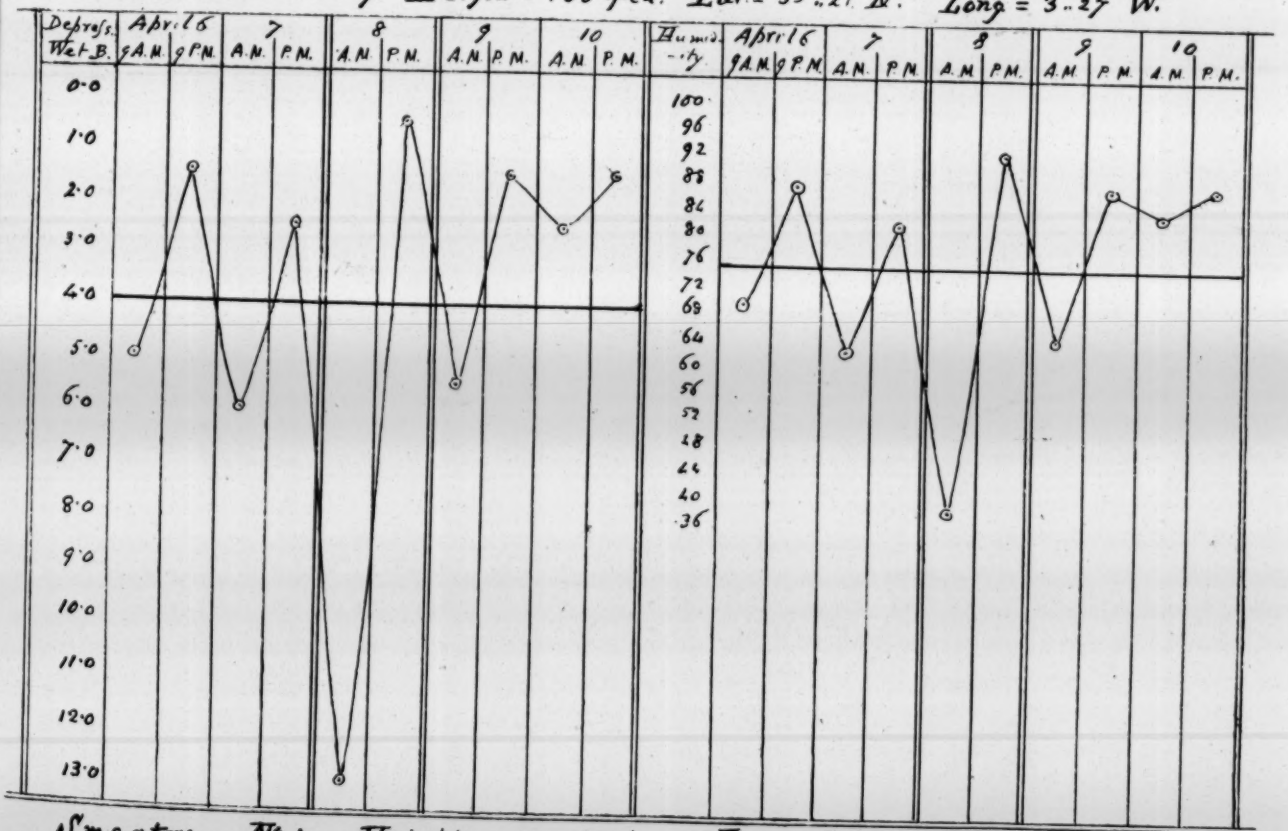
Cupar (Fife) № 11. Height = 210 feet. Lat = 56° 10′ N. Long. = 3° 6′ W.



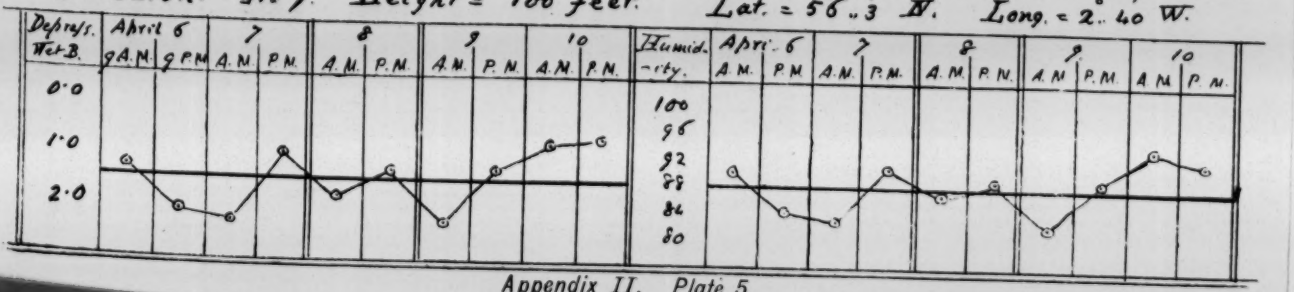
DalKeith (№ 6) Height = 190 feet Lat = 55° 54′ N. Long. = 3° 4′ W.



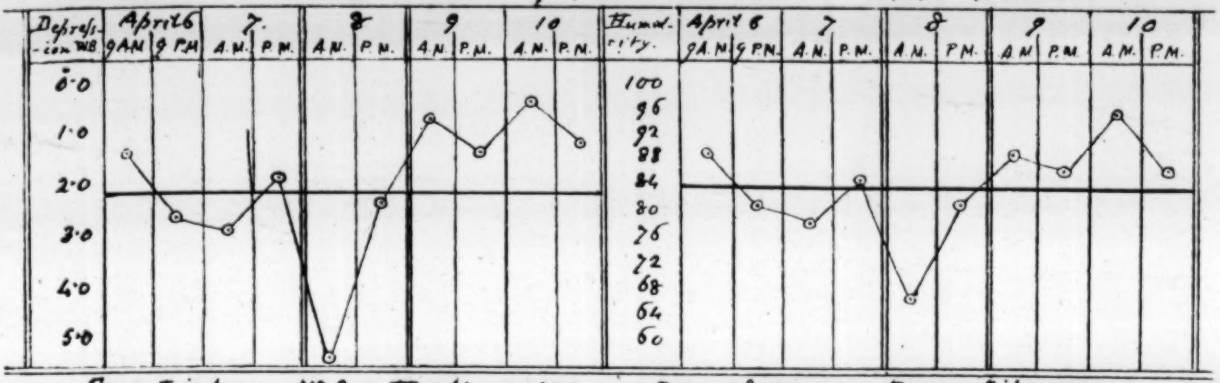
Callton-Mor. № 19. Height = 135 feet. Lat. = 55° 21′ N. Long = 3° 27′ W.



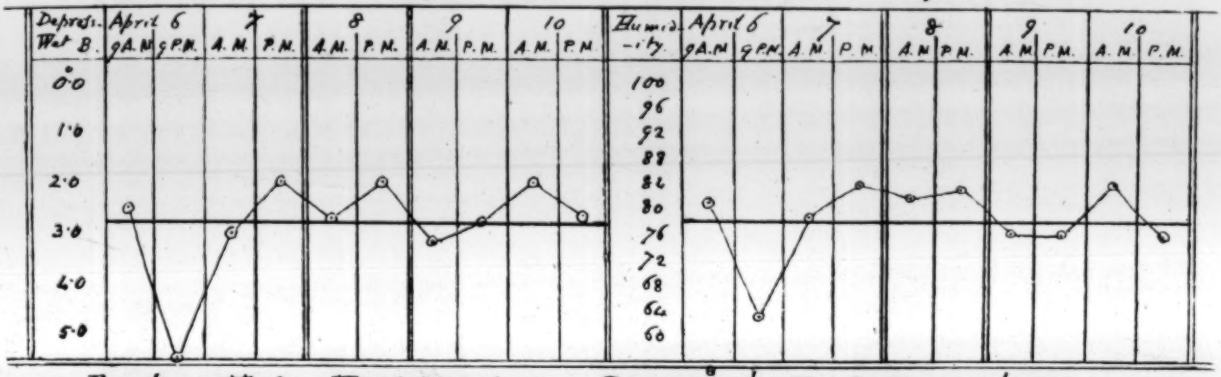
Smeaton. № 7. Height = 100 feet. Lat. = 56° 3′ N. Long. = 2° 40′ W.



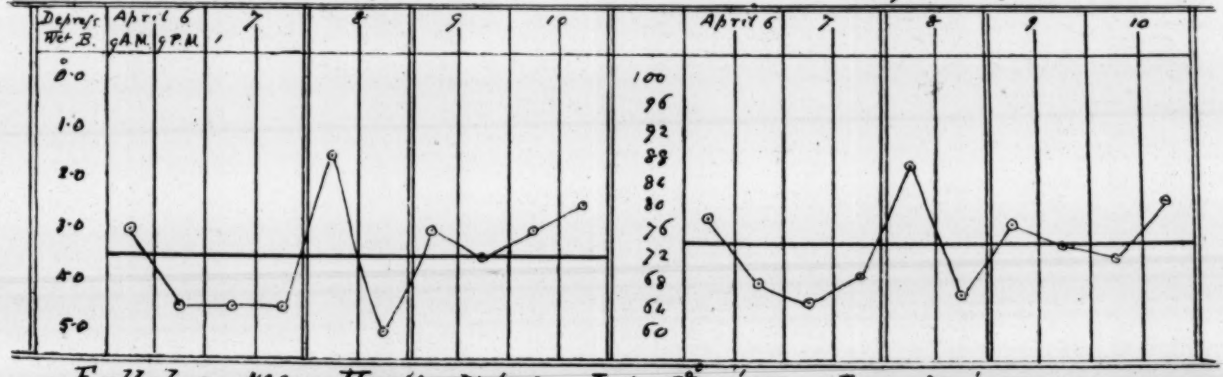
Balloch Castle. № 13. Height = 93 feet. Lat. = 56°. 1 Long. = 4° 35 W.



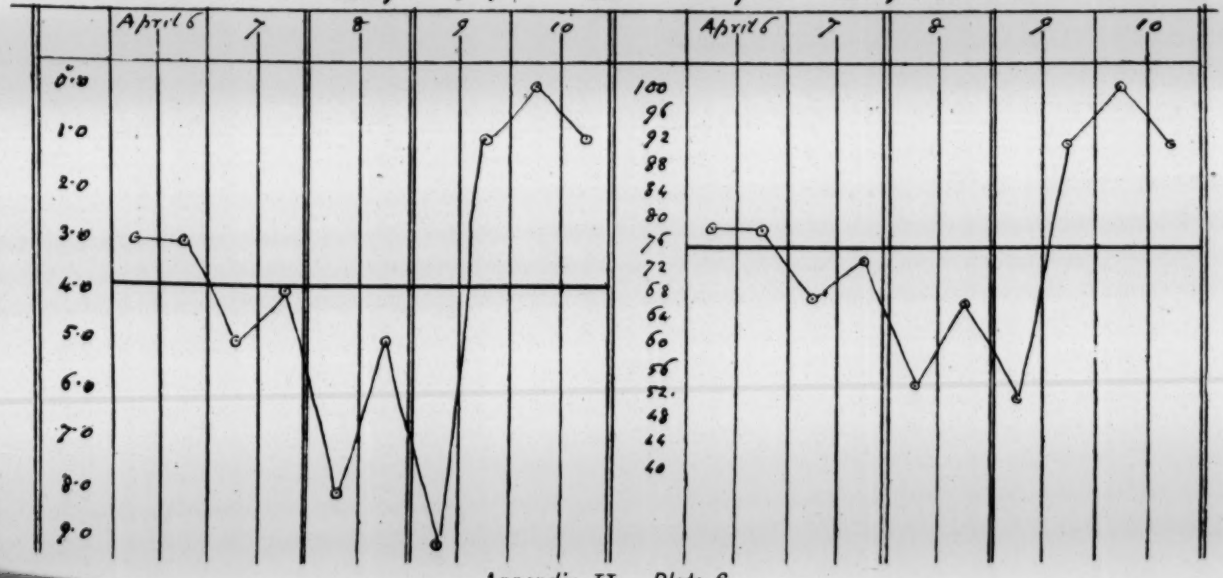
East Linton. № 8. Height = 90 feet. Lat. = 55°. 59 N. Long. = 2°. 16 W.



Paisley № 18. Height = 88 feet. Lat. = 55°. 50 N Long. = 4°. 27 W

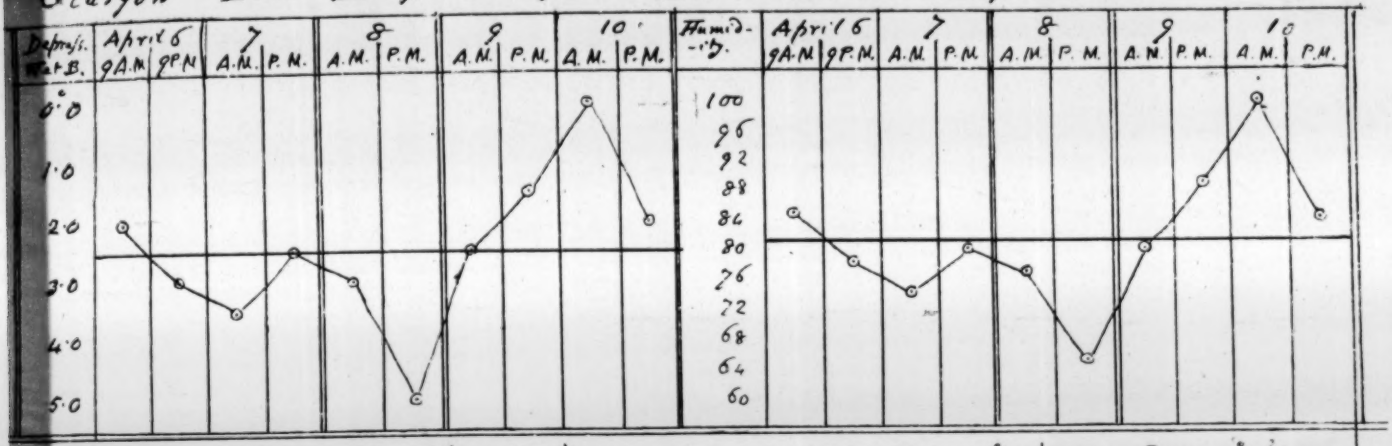


Eallabus № 20. Height = 71 feet. Lat. = 55°. 47 N. Long. = 6°. 15 W.

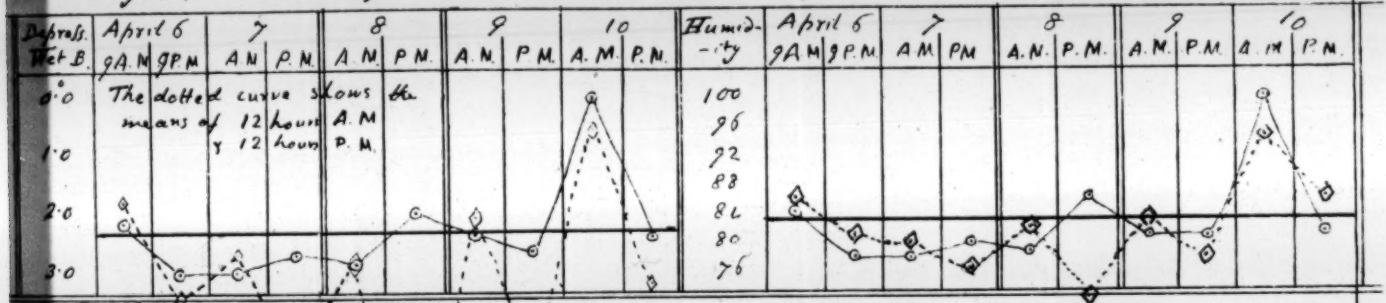


Appendix II. Plate 6.

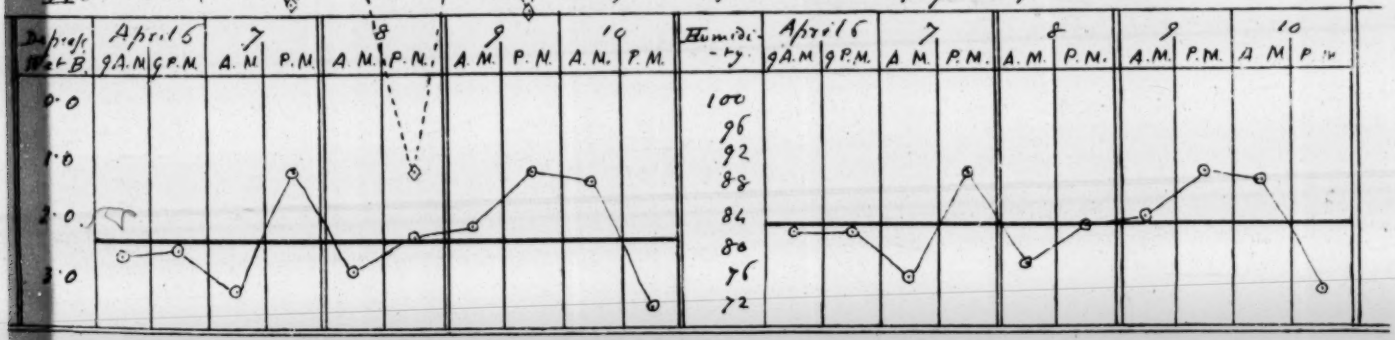
Glasgow No. 12. Height = 54 feet. Lat. = 55° 53′ N Long. = 4° 18′ W.



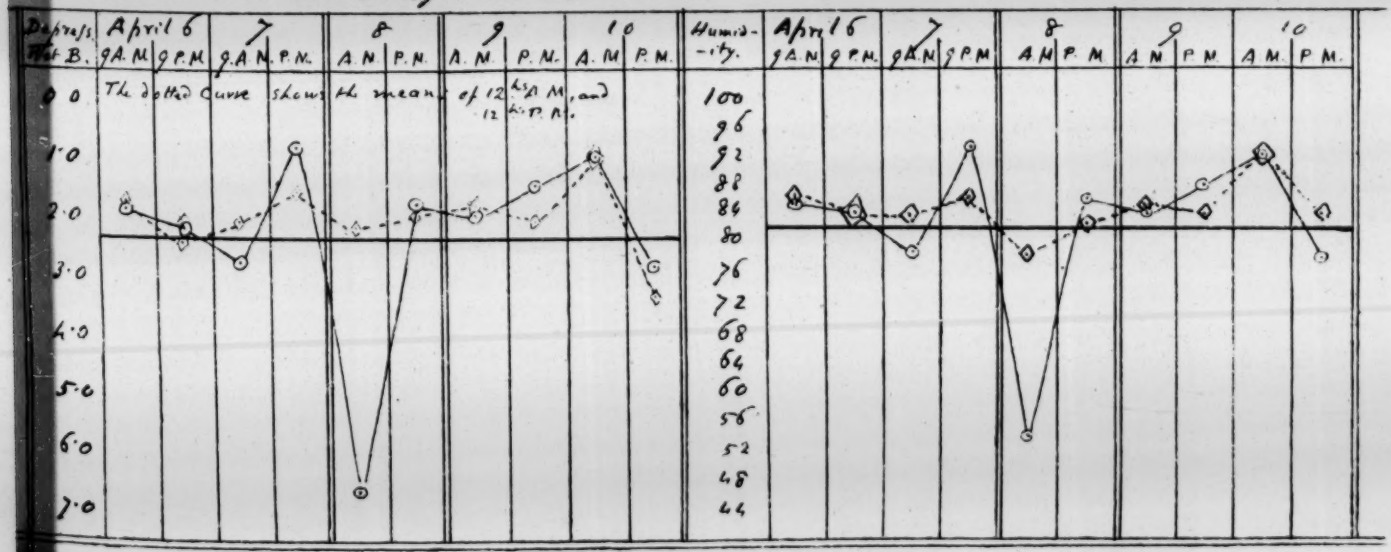
Glasgow, Meteorologic Council No. 26. Height = feet. Lat. = 55° 53′ N Long. = 4° 12′ W.



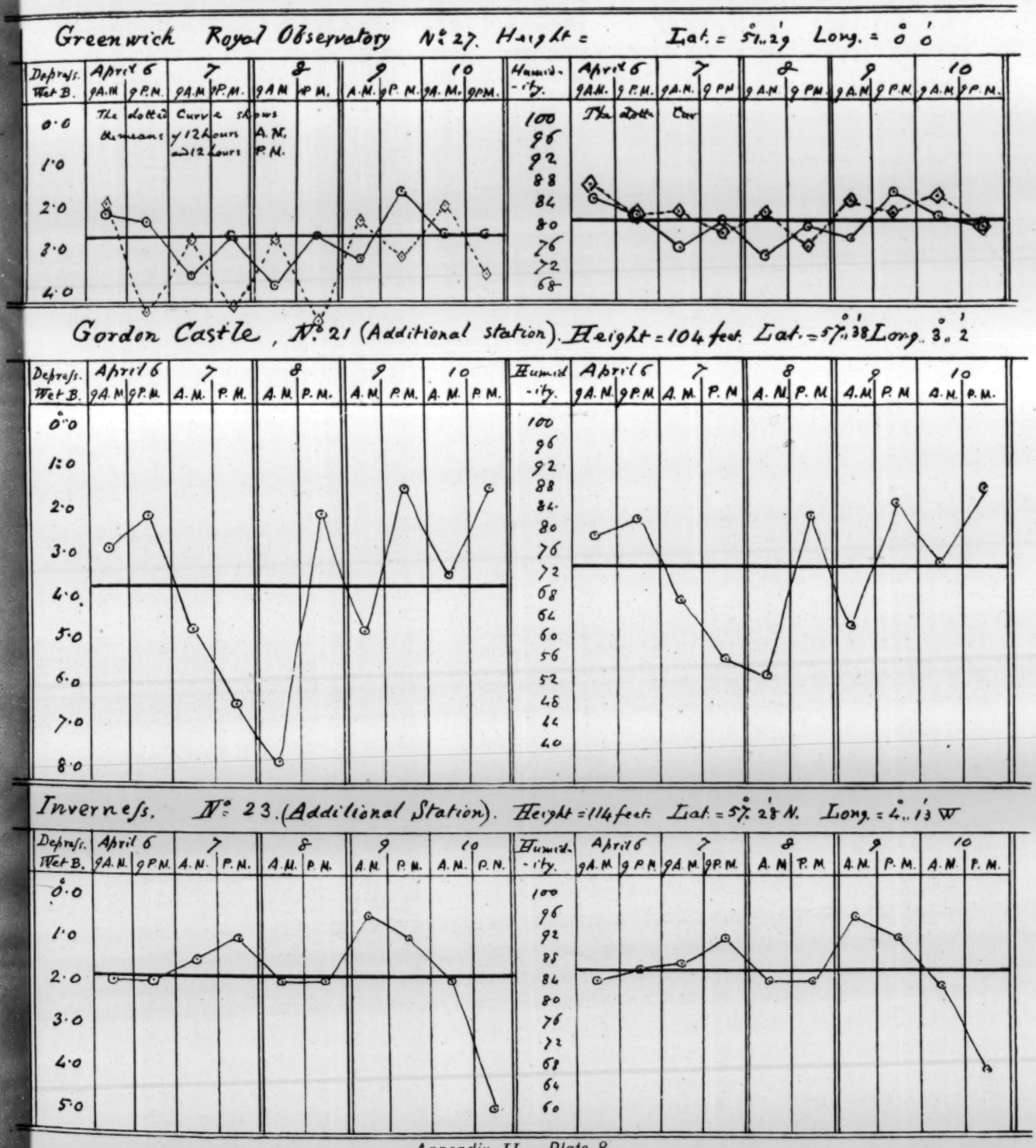
Aberdeen (Additional Station No. 2) Height = 66 feet. Lat. = 57° 9′. Long. = 2° 6′ W.



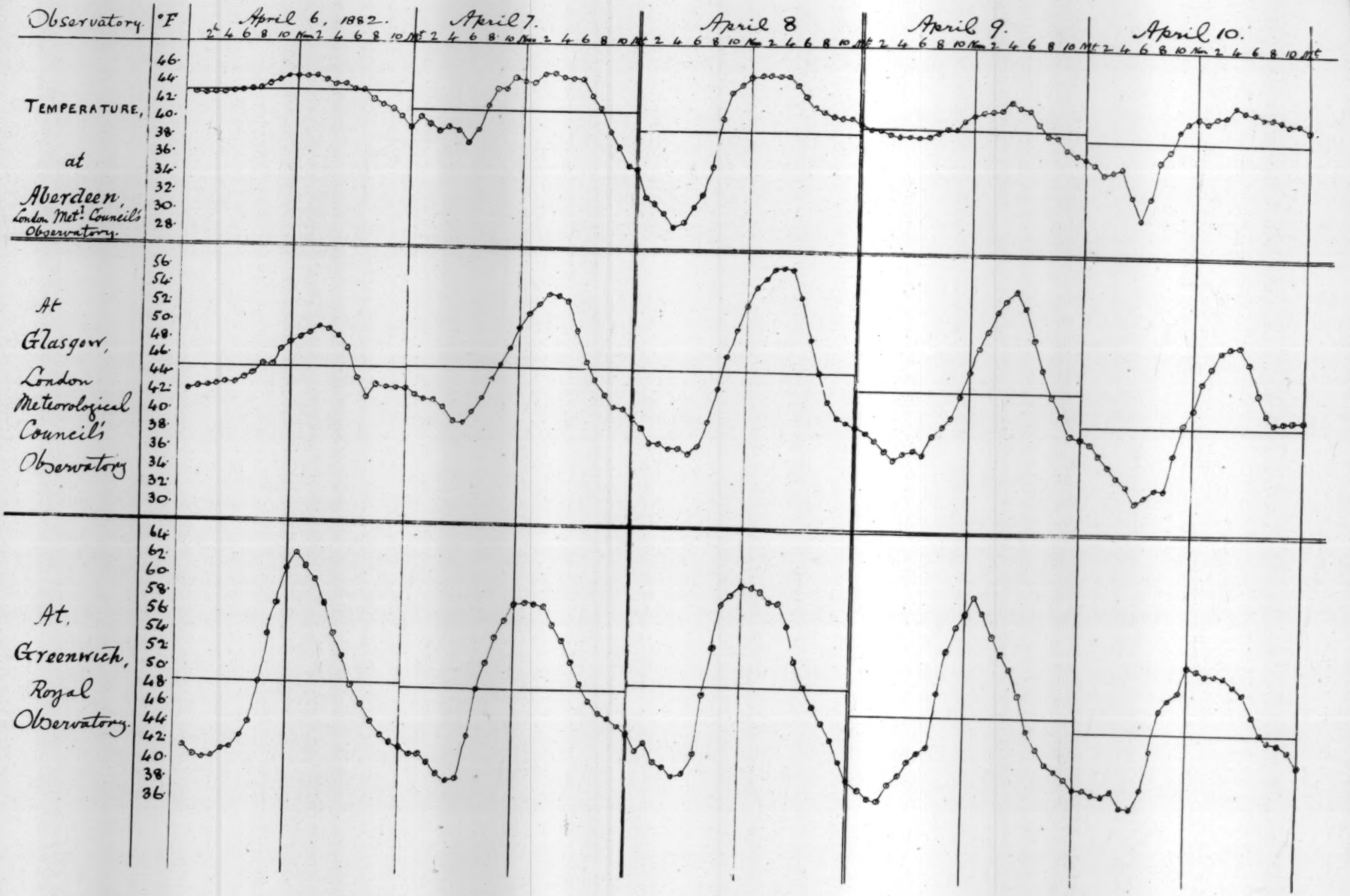
Aberdeen, Meteorologic Council No. 25.

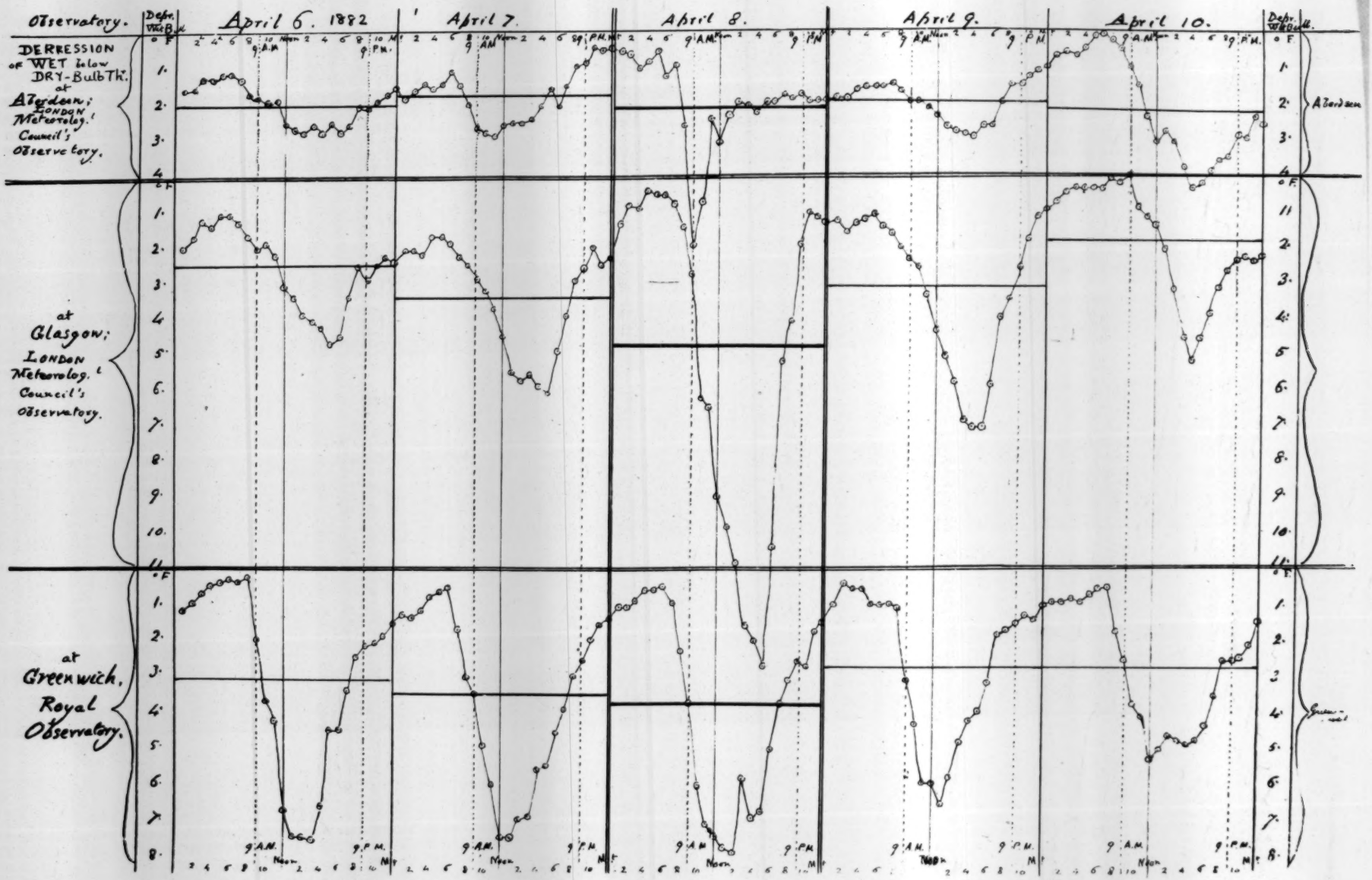


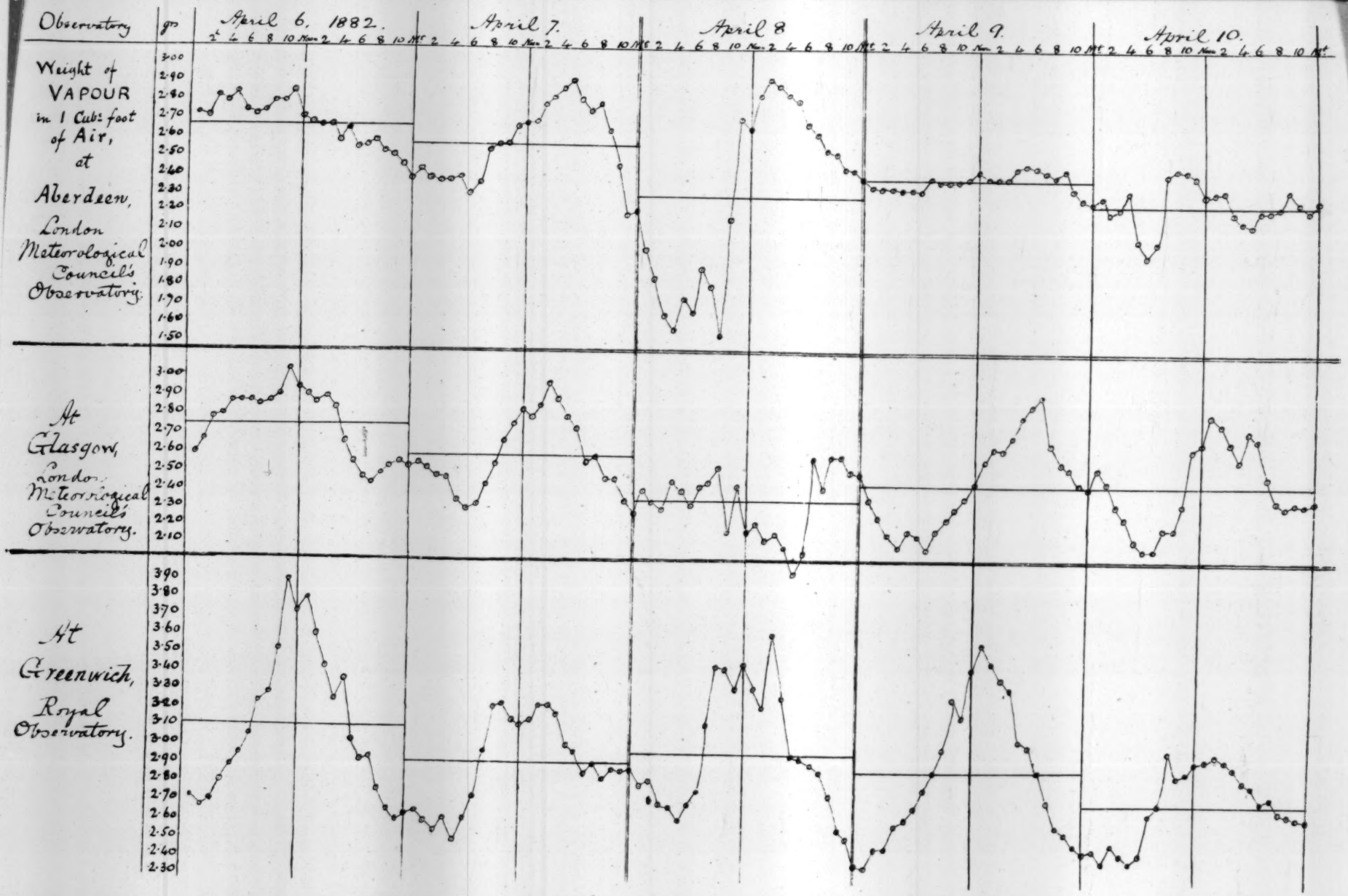
Appendix II. Plate 7.

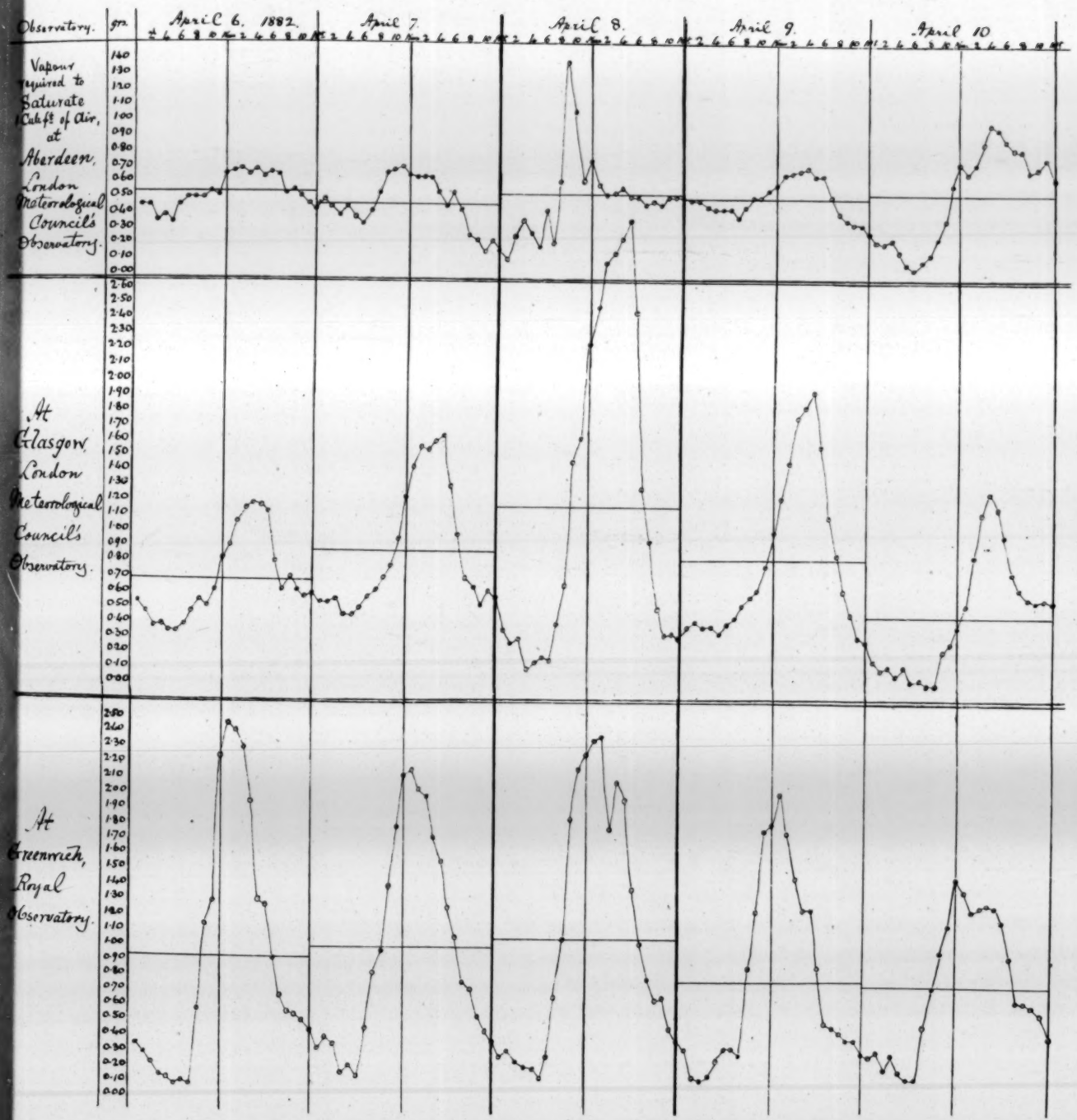


Appendix II. Plate 8.


Observatory
°F
April 6, 1882.
April 7.
April 8
April 9.
April 10.
TEMPERATURE,
at
Aberdeen,
London Met. Council's Observatory.
At
Glasgow,
London
Meteorological
Council's
Observatory
At,
Greenwich,
Royal
Observatory.


Observatory.
April 6. 1882
April 7.
April 8.
April 9.
April 10.
DEPRESSION of WET below DRY-Bulb Th.
at Aberdeen; LONDON Meteorolog.l Council's Observatory.
at Glasgow; LONDON Meteorolog.l Council's Observatory.
at Greenwich, Royal Observatory.
Aberdeen
Glasgow
Greenwich
9 A.M.
9 P.M.
Noon


Observatory
grs
April 6, 1882.
April 7.
April 8
April 9.
April 10.
Weight of VAPOUR in 1 Cubic foot of Air, at Aberdeen, London Meteorological Council's Observatory.
3·00
2·90
2·80
2·70
2·60
2·50
2·40
2·30
2·20
2·10
2·00
1·90
1·80
1·70
1·60
1·50
At Glasgow, London Meteorological Council's Observatory.
3·00
2·90
2·80
2·70
2·60
2·50
2·40
2·30
2·20
2·10
At Greenwich, Royal Observatory.
3·90
3·80
3·70
3·60
3·50
3·40
3·30
3·20
3·10
3·00
2·90
2·80
2·70
2·60
2·50
2·40
2·30


Observatory.
gr.
April 6. 1882.
April 7.
April 8.
April 9.
April 10
Vapour required to Saturate 1 Cub^{ft} of Air, at Aberdeen, London Meteorological Council's Observatory.
At Glasgow, London Meteorological Council's Observatory.
At Greenwich, Royal Observatory.

Observatory.
HUMIDITY:
at
Aberdeen,
under Meteorological
Council's Observatory.
At
Glasgow,
under
Meteorological
Council's
Observatory.
At
Royal Observatory
Greenwich,
from
Photo Records
of 1882.
April 6, 1882.
April 7.
April 8.
April 9.
April 10.
100
97
94
91
88
85
82
79
76
73
70
67
64
61
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55
52
49
46

III.—*Note on the Little* b *Group of Lines in the Solar Spectrum and the New College Spectroscope.* By C. Piazzi Smyth, Astronomer-Royal for Scotland. (Plate XV.)

(Read June 1883).

Every spectroscopist is perfectly aware that the group of dark Fraunhofer lines in the Solar Spectrum, known as "little *b*," is composed of the biggest, broadest, most colossal lines in all the brighter part of any and every spectrum depending on Sunlight, whether direct from the Sun or reflected from the earth's atmosphere, the Moon, or any of the planets.

How the apparent misnomer came about, was not on the principle of the biggest gun ever made by our military, being termed "the Woolwich infant;" but because after Fraunhofer had spaced out the spectrum into nearly equal lengths, so far as the majority of the chief lines allowed, and called them by capital letters, beginning with great A in the ultra red and ending with great H in the ultra violet,—he then began again at the red end, and marked all the notable intervening lines by small letters. Whence it came about that those sometimes very imposing bands of telluric water-vapour lines "little *a*" are found between great A and great B; and those grand and truly solar lines in the green, little *b*, are found, by accident as it were of Nature, between great E and great F.

In the smaller class of pocket spectroscopes and on the faint light of the Sky, observers merely recognise two strong lines; the first from the red end is b^1, and the second, considerably thicker, is b^2. A very little increase of power, however, easily shows b^2 to be composed of two lines, b^2 and b^3; and Fraunhofer himself had announced it. But that such b^3 was still further composed of two lines was I believe first discovered by Professor Swan, and published in our *Transactions* as part of his now classical spectrum paper of 1855 and 1856. For therein (vol. xxi. p. 427) he mentions most clearly—though calling our b^1, b^2, b^3 by the names *b*, b^1, b^2 that "on the 20th of May, about 7^h 10^m P.M. when the sun was rather low on the horizon, but free from clouds, he observed with a magnifying power of 21 (on his large theodolite telescope, directed to a single prism of 60°) the line b^2 (our b^3) to be very finely but distinctly double; so that," he adds, "the group consists of 4 lines" (our b^1, b^2, b^3, and b^4). While on page 426 he had already expressed his admiration for the group "as being one which, whether we regard the singular configuration or the strength of the lines which compose it, is perhaps the most notable in the solar spectrum."

In the *Philosophical Transactions of the Royal Society* (London) for 1860,

there is a picture by Sir DAVID BREWSTER and Dr GLADSTONE confirming these four grand lines of little *b*, and adding some thinner intervening lines and faint broad bands. But before that could produce much effect on men's minds, it was utterly eclipsed by the far grander Solar Spectrum map, first of Prof. KIRCHOFF, and then of Professor ANGSTROM, whose exquisitely engraved, and certified, map still remains for many purposes the Normal Solar Spectrum Map of all the human race.

Now let us take a new start from that last map, date 1868, in order to ascertain something of our present degree of knowledge touching the visible characteristics of these four remarkable lines; for however many thinner ones there may be, the principal members of the group are four only, and have overwhelming importance. Two of these moreover, viz., b^1 and b^2 were represented by ANGSTROM physically different from the others, by slightly bordering them with haze.

In 1875 the Royal Society published a map in their *Philosophical Transactions*, where they represented (though by a very exceptional kind of symbolic marking, looking really like something else very different but very important if true) these haze borders of b^1 and b^2 as still broader; but made b^3 and b^4, pale in a high, dark in a low, sun, as though they were atmospheric or telluric lines, which they certainly are not.

In 1880 M. FIEVEZ, in the R. Observatory of Brussels, represented several lines hazy, though he left b^4 quite sharp and black.

But in the same year Professor VOGEL, of the Astro-Physicalischen Observatory at Potsdam in Prussia, and armed with a new spectroscope of immense power, published a very superior spectrum map wherein he represented b^1, b^2 and b^4 all equally and very broadly hazy, but kept b^3 quite sharp, well defined and black, besides adding many thin lines, some single and others double.

In the following year at Madeira I had the opportunity, besides confirming Professor VOGEL on all the four great lines, of adding thereto the further physical distinction that the lines themselves, inside the envelopes of haze of b^1, b^2 and b^4 were all of a peculiarly faint material; and of presently still further discovering both that the b^4 line, within the compass of its own haze, was double; and that b^3, without any haze, appeared not actually double, but to promise certain resolvability into it, had my apparatus been only of a slightly better order.

At the time I could hardly believe my eyes; but have learned since then that the duplicities of b^3 and b^4 had been just previously to that date ascertained with some of the splendid spectroscopes in America; as they were also subsequently by a second very powerful spectroscope built up, and employed by M. FIEVEZ at the Royal Observatory, Brussels, in 1882.

But perhaps I am going on too fast; for certain learned parties, to whose

extensive knowledge implicit respect has hitherto been generally paid, have not yet taken any notice of either M. FIEVEZ or the American observers. A particular case of such neglect is to be found in the new, or third edition, of Dr SCHELLEN's German work on "Spectrum Analysis" published during the present year, 1883, in 2 volumes, and an atlas filled with excellent engravings.

The number of different spectroscopes illustrated in those volumes is legion. But amongst them all, the highest opinion seems to be entertained for the spectroscope of Professor VOGEL, already alluded to. The instrument was made by the celebrated M. SCHRODER of Berlin, contains 6 large compound prisms of heavy glass, with powerful telescope, collimator and automatic movements to match. It is represented accordingly with pride in three pictures on pp. 243, 244 and 245; while on p. 247, to prove beyond doubt how advanced are its powers, a pair of diagrams of the little *b* group are given; first, as they were represented by ANGSTROM in his day; and second, as they are now seen by Professor VOGEL. But though the latter, as I have already stated, introduces several more thin lines, he leaves the four classic members of the little *b* group, as given by ANGSTROM at the early spectroscopic date of 1868, untouched; for Dr SCHELLEN, by some inadvertence having imparted haze to ANGSTROM's view of b^4, has destroyed (on his own plate) the rightful claim of Professor VOGEL to that physical discovery.

Now let us contrast that state of things with some observations I have just been able to make in Edinburgh through the sunshine there, all smoky as it unhappily is, at No. 15 Royal Terrace, but with an admirable spectroscope, kindly left in my hands for a few weeks by Professor P. G. TAIT,—after he had, by a marvellous chance, been able to acquire it for the Natural Philosophy Laboratory of the Edinburgh University. It is of English make, by Messrs T. COOKE & SONS of York, but constructed for the late eminent Belgian scientist, Dr VAN MONCKHOVEN, on a plan arranged between himself, Mr LOCKYER and Messrs COOKE; though he had hardly received it when sudden death by *angina pectoris* cut short his splendidly energetic and promising career, to the terrible grief of his family and friends. The instrument thrown thus open to purchase again, was sent here by Messrs COOKE, and I could not but admire exceedingly the compactness of its arrangement, by which it was enabled in a remarkably small compass and with absolute directness of vision throughout the whole spectrum, to employ virtually any number of prisms from 2 to 20. Every prism too being "simple," and of white flint glass; a feature in happy opposition to the compound prisms of brown or green flint glass, cemented to crown-glass anti-prisms, which are far too frequent favourites elsewhere.

But how did the Cooke spectroscope acquit itself, when tried with the maximum number of its prisms, and highest magnifying power of eye piece? I was over and above delighted to find that it focussed more sharply than any

spectroscope I had ever used; and on bringing in our old friends of the little b group, there was not only all that Dr SCHELLEN and Professor VOGEL have recorded for the latter—not only too all the physical features which I had noted with difficulty at Madeira,—but there were b^3 and b^4, each of them as clearly doubled, and their components clean separated, as any observer could possibly desire. Of b^3 one line was shown to be much stronger than the other, but equally sharp; while of b^4 one line, the stronger also of the pair, was evidently hazy, and just as accurately concentric with that cloud of haze, as were the old b^1 and b^2 with regard to their clouds of haze; but the new and weaker component of b^4 was evidently excentric to the haze of b^4; a further test now of performance, but whose additional utility will presently appear.

So far then as mere optical definition was concerned, nothing could be more satisfactory, or rather I should say transcendent, than this trial of the new College spectroscope on the little b group; though it had been preceded in its detection of duplicities merely, by the American observers, and also by M. THOLLON in France, and M. FIEVEZ in Belgium. But those gentlemen have not, so far as I know, taken the further step of investigating chemically and physically the ultra nice points of optical discovery which they have added to the b group.

I do not of course by this allude to what every one may read in ANGSTROM'S admirable normal map, as to b^1, b^2 and b^4, all of them now known to be endued with a remarkable haze, being the reversals of magnesium metal burning in the Sun, and b^3, so strikingly without haze, being a similar representative of iron; —but to this further detail, that under and coincidently with b^4, ANGSTROM placed an iron, *as well as* a magnesium line; and under b^3, a nickel, *as well as* an iron line. Or, as his followers are delighted to assert, b^3 and b^4 are basic lines; viz., one line standing as a base for two metals. The principle therefore of any such basic line represents a new chemistry, where two earthly elements are, by long roasting in Solar heat, resolved into one element, forming a common base to them both. So that certain reputed simple and original elements of the chemists hitherto, are really compound bodies; and the list of elements in the Sun, is shorter than that which is accepted on the earth.

It is something of a check to that system, to be enabled to say from mere optical observation, that in the two instances in little b, where basic lines had been thought to be met with, superior spectroscopes have shown there are two lines in each case; but much more than that is necessary for full proof; for who can be certain that any two given spectrum lines seen very close together, in place of representing a mere chance, or optical, coincidence of two perfectly unconnected elements' lines, may not be a physically double line of some one metal.

I have therefore been trying the Cooke Spectroscope on this point, by

deflagrating before it with condensed induction spark the several metals concerned. My apparatus for that purpose is unfortunately very primitive and weak, not more than 1·5-inch sparks in air, and 1 quart Leyden jar to condense; but by placing the spark in front of the slit, obtaining the solar spectrum between the points of the sparking metals, and correcting by eye for the necessarily curved spectral lines of 20 simple prisms,—certain definite results were obtained on some of the points required, as thus—

(1) For Magnesium. The metal spark line corresponding to b^4 is just as certainly a single line, as those corresponding respectively with b^1 and b^2; and further it falls on the second, more refrangible, and stronger component of the Solar b^4, quite suitably to its hazy physical appearance in the Sun.

These three Magnesium spark lines moreover form an ordered triple, remarkably like the Oxygen triples which I announced to the Society some two years ago, in so far that the 2nd and 3rd are closer together than the 1st and 2nd, and the intensities of each go on decreasing from 1st to 2nd, and from 2nd to 3rd, but the arrangement is on a far grander scale.

(2) For Iron. Two of its spark lines appear in the field of view in places evidently belonging to b^3 and b^4 in a general way; but they are both sadly faint, *i.e.* in my weak sparking apparatus. However the stronger one is remarkably sharp and may be certainly said to coincide with the first, or least refrangible component of b^4 in the Solar spectrum; which is that one which simple observation had already shown to be excentric to the characteristic magnesium haze. With not by any means so much certainty, unfortunately, the fainter iron line may be said to coincide with the stronger of the two recently discovered components of the Solar b^3.

(3) For Nickel. Here the result was poor to utter disappointment; the tabular Nickel line concerned has only an intensity of 2 attributed to it, against many that are classed as 10, by the great spectroscopists with powerful apparatus; and it appeared to me to deserve even less. Indeed I had only to wander a little further on into the blue regions of the spectrum to find Nickel lines there that were a pleasure and a certainty to compare with Solar lines; but the particular Nickel line in or near b^3 was so faint as to be utterly hazy and undecided; wherefore I must relegate this question of the b^3 supposed basic line to those who can produce brighter sparks of Nickel and Iron than I can.

And there is another point touching Nickel that I would also recommend to their earnest attention. Every one has heard of the Nickel line between the two D lines of the Solar spectrum; and many persons will have read in Dr Marshal Watt's most useful Index of Spectra that both Thalen and Kirchoff have assigned their maximum for intensity, or 10, to that Nickel line. Being desirous therefore to see what such a grand line would look like in the Cooke spectroscope when sparked by my apparatus, I brought it into the

field, together with the Sun spectrum; but behold, although it was much clearer than the little b^3 Nickel line, it was yet a very poor thing; so poor, that I wandered off into the Citron regions, amongst the groves of hazy air lines, to see if something better could not be found there; and sure enough I stumbled almost immediately on a magnificent line, a line which for brightness, beauty and definition was far beyond everything else in the field of view, though that was a pretty full one too. It proved to be the line at 46 380 W.N. Place, which Dr WATTS has entered in his tables on the authority of both THALEN and KIRCHOFF as of intensity only equal to 6, when the trifling line between D^1 and D^2 was called by them 10.

On turning to ANGSTROM'S Normal Solar map with its chemical references, I was encouraged by finding the D Nickel line and its Solar representative also, far fainter than the 46 380 W.N. line of Nickel and *its* Solar reversal. But on still further referring to that most able observer M. LECOQ DE BOISBAUDRAN, he represents the 46 380 line, as the very maximum, or the a, of the whole Nickel spectrum; gives no place to the D Nickel line at all; and only the faintest imaginable marking to the Nickel line in the place of b^3. His deflagrating method was however different; for he used simple, uncondensed electric sparks, and employed them not on metal points, but on a solution of a salt of the metal. Perhaps too, bearing in mind the extreme modesty of his "spectroscopic installation," it is wrong to refer to him,—master hand though he undoubtedly is, so far as it accords with his plan to go into any subject,—for more than the testimony he gives to the magnificent lustre of the a line at 46 380 W.N. Place. So that the only remaining anomaly, but a most important one, to be cleared up by those who have plenty of electrical energy at their command and a good spectroscope, is, the immense intensity attributed to the D Nickel line by MM. THALEN, KIRCHOFF and WATTS! Is there a numerical error there, or is that line capable of peculiar intensification with increased electric temperature?

But meanwhile though I may have failed in *that* inquiry, what an extension of the powers of pure and simple spectroscopic observation (when we have light enough) does not the new College Spectroscope already exhibit!

A few years ago some of our best men thought the *ne-plus-ultra* of accurate observing had already been reached with the Dispersion of a single prism of 60° and magnifying power on a telescope of about 20: for after that, they found that whatever was gained in Dispersion by adding a second or third prism, was lost by bad definition. But here, thanks to the super-excellence of our British optical house, Messrs T. COOKE & SONS of York, no less than 20 prisms are virtually employed, and the limits of fine definition, even when tested by high magnifying power, are not yet reached.

All that Dispersive power too, and all that Definition are perfectly necessary

in the present day. For as this Note must have shown, if it has shown anything, the most radical and fundamental questions in all Chemistry and the very constitution of the Cosmos depend upon the most recently elicited and minutest of all the phenomena yet observed.

P.S. September 28, 1883.

The above position will become still more distinct on considering two sets of first rate observations in this part of the Spectrum, contained in the *Proceedings of the Royal Society* (London), and the present paper should by no means be allowed to close without honourable mention of both of them.

The first to be noticed of these sets, is by Professors LIVEING and DEWAR, working in the magnificent Cavendish Laboratory at Cambridge; and writing at p. 229 of said *Proceedings* for May 1881, of b^3, that it is "a close double, but the Iron is less refrangible than the Nickel, line."

While of b^4 they state with greater fulness:—

"By examining the arc of a battery of 40 Grove cells, or that of a Siemens' machine, taken in a crucible of lime, under the dispersion of the spectrum of the fourth order given by a Rutherfurd grating of 17,296 lines to the inch, we are able to separate the iron and magnesium lines which form the very close pair b^4 of the solar spectrum. Either of the two lines can be rendered the more prominent of the pair at will, by introducing iron or magnesium into the crucible. The less refrangible line of the pair is thus seen to be due to iron, the more refrangible to magnesium. Comparison of the solar line and the spark between magnesium points confirms this conclusion, that the magnesium line is the more refrangible of the two."

This accords well enough with, and indeed overshadows, my imperfect experiments in Edinburgh. But what are we to think, on turning to p. 443 of the same Society's *Proceedings* for the earlier date of March 20, 1879, where that distinguished spectroscopist Mr NORMAN LOCKYER, working with all the resources of the Government Department of Science and Art at South Kensington, implies, of b^3, that there is no Iron there, only Nickel; but of b^4, that there are besides Iron and Magnesium, no less than 9 other metals, viz., Mo, W, Co, Mn, Ca, Li?, Na?, Cu, and Al, coincident with it.

The beginning of some explanation of this difference undoubtedly is, that at the time of his observation, the accomplished observer had not heard that both b^3 and b^4 were double lines, and had not a spectroscope of sufficient power to show them so.

The second part of the explanation is probably due to the admission in the last par. of p. 442, that compulsory "rapid surveys of the arc spectra of most of the metallic elements" have led to approximate, being sometimes assumed as exact, coincidences.

This is an almost necessary feature in the earlier stages of any inquiry; but now that we are happy to learn, on one side, that Mr LOCKYER has come into possession of one of Professor ROWLAND's (U.S.Am.) grand concave Gratings, and on the other, know that the Natural Philosophy Laboratory of the Edinburgh University possesses the Monckhoven-Cooke Spectroscope, together with a 4-horse power Gas-engine, Dynamo, Grand Induction-Coil and Condenser to suit,—we may expect something very important from either one or both those parties revising that list of so many metals supposed, four years ago, to have one common meeting place in the Spectrum.

C. P. S.

EXPLANATION OF THE PLATE REPRESENTING THE COURSE OF DISCOVERY TOUCHING THE LITTLE b GROUP IN THE SOLAR SPECTRUM.

This plate is rough and rude to a degree, and that is partly intended; because, to attempt to reproduce the infinite refinement of shades, tints and lines shown by Nature in the Solar spectrum, belongs more to the department of artistic beauty, than scientific work; and already every high Solar scientist has utterly discarded the trouble and expense of introducing that leading element of the Spectrum's beauty, colour, into his maps; and has taken that very strong step towards a symbolic, rather than realistic, representation, partly on account of the absence of colour-pigments from his paper enabling him to bring out the more useful black or grey of the Fraunhofer lines with greater force and more ease of recognition.

But even then, in mere black and white, the question comes up once again, should we attempt to reproduce *every* such refinement the spectrum itself shows, and in the *manner* in which it appears there,—which would necessitate the most ultra microscopic engraving on

copper or steel plates;—or shall we adopt a short, easy, symbolic method by which in the tenth of a second we can make a mark anywhere, on paper as well as copper-plate, signifying merely, or standing for, such and such an artistic, or realistic, effect?

A splendid example of the former method is to be seen in M. CORNU'S fine engravings of the ultra-violet portion of the Solar Spectrum; for there, thin lines are successfully represented of every degree of shade from lightest to darkest; but without the mechanical means by which they are executed appearing to the eye, until reinforced by a powerful magnifying glass; and they are then seen to be the effect of minute dots more or less closely packed, and without ever recurring to "the vulgar expedient" of ruling an actual line, in one uniform degree of blackness. When any person donates the science of his time with such a Solar spectrum map, whether in whole or part, the public ought to be very grateful to him; and it is to be hoped they are so, in this case, to M. CORNU, the distinguished Parisian scientist, for his unmatched portraiture of "the region of fluorescence."

But the daily work of the world requires an *interim* employment of some easier method, something akin to writing by the letters of the alphabet as signifying sounds, in place of painting pictures of the things intended. One method already extensively in use and much to be commended, is to express the different degrees of darkness of a Fraunhofer line, whatever the breadth, by different *heights* or *depths* of the line; and this it will be seen I have availed myself of in several instances.

The same principle may be applied to the shadings by which bands are represented in the Spectrum. Shadings of some kind are necessary there with the very faint bands, to prevent straining the symbol too far; which would result, if we had only the device of shortening the height of a band in positive black ink, to represent an ultra faintness of shade. Such shade being, in reality, at the telescope, just as high necessarily as any of the blackest lines, because they are all reproductions of one and the same slit in front of the spectroscope.

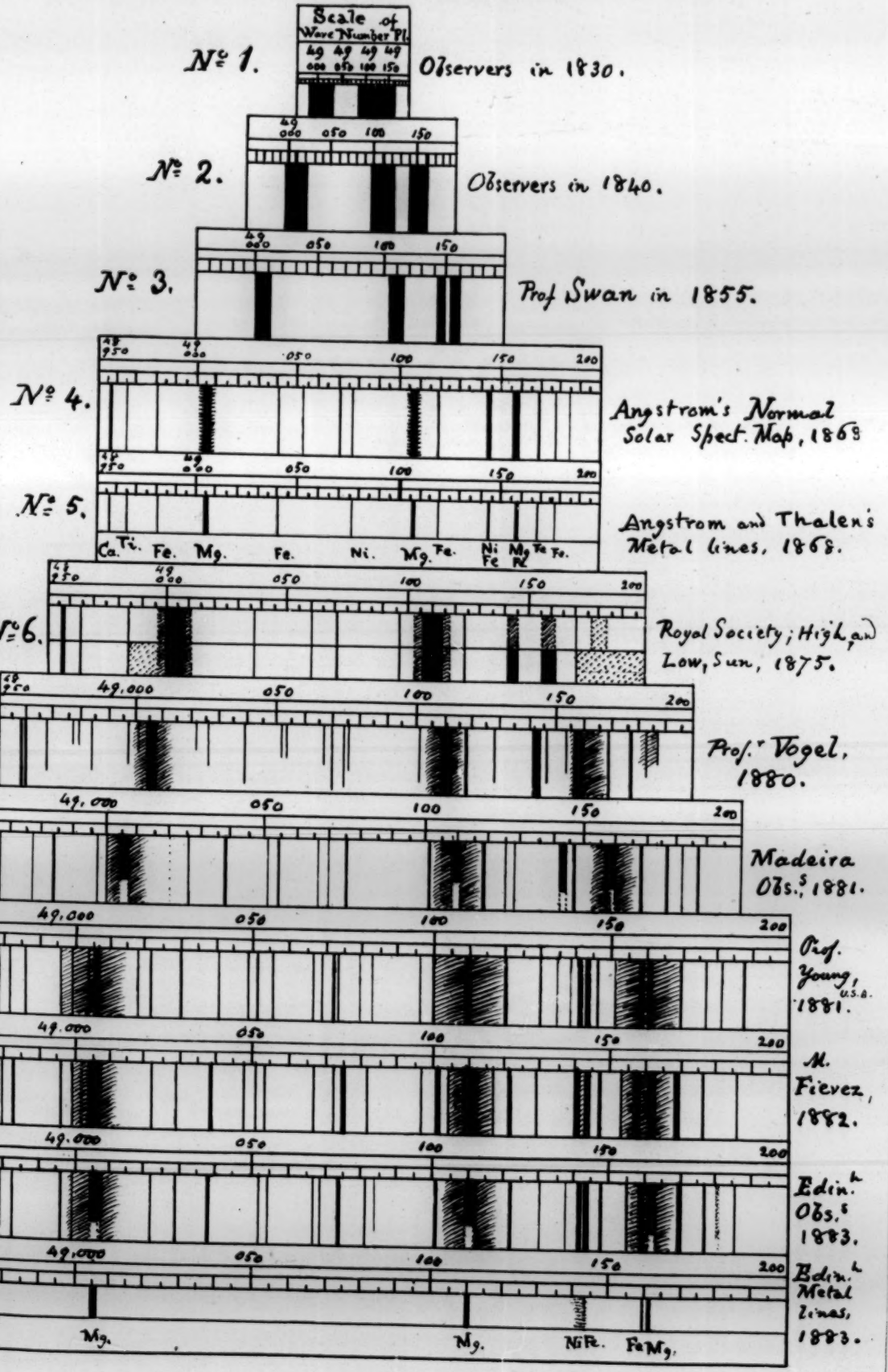
Faint bands therefore have long since been generally represented by a shading of thin parallel lines; and the method is unequivocal when the lines are ruled in any direction except that, in which they might be repetitions of the slit of the Spectroscope, or stand for separate, independent, thin Fraunhofer lines.

Hence I have represented the hazy borders of the *b* lines, by either horizontal, or 45° inclined lines, and no spectroscopist will take them, or the knots in them, as anything else than symbols of shade. It is necessary too, to be very particular on this point, because the Royal Society, London, in both its Philosophical Transactions and Proceedings, has most pertinaciously set, and is still setting, the opposite example of representing shade in the spectrum, by thin lines ruled parallel to each other and *in the direction of the slit;* so that when many and many a close double, or treble, or quadruple Spectral line appears in a Royal Society engraved Spectrum plate, it may mean, either that their observer did see a double, or treble, or quadruple line in that place; or, that he only saw a faint, unimportant haze.

Finally in our present plate, one more difficulty has to be compassed; for it is to be an historic memento, from the earliest spectroscopic times to the latest. In my last year's publication, "Madeira Spectroscopic" I attempted to meet a similar case, by representing every observation, of whatever date, on one and the same scale. But I have been told that some persons do not like the necessarily resulting effect of that plan, in so far as it makes the earlier observations, taken with very small dispersive power, look colossal in coarseness. In the present case therefore, I have decreased that appearance by adopting a smaller and smaller scale for every earlier Spectrum view; but so arranging them one over the other, each with its own sized numerical graduation above it, that I trust there will be the least difficulty and the most satisfaction practically possible, in comparing details of the one with the other, and fixing the dates when real advances of observation—knowledge were made.

C. P. S.

Chronological Plate of the Course of Discovery, touching the little b group in the Solar Spectrum; 1830 – 1883.



IV.—*Observations on the Annual and Monthly Growth of Wood in Deciduous and Evergreen Trees.* By the late Sir ROBERT CHRISTISON, Bart., and Dr CHRISTISON.

(Read 19th March 1883.)

Having undertaken to continue the observations on the growth of trees commenced by my father in 1878, and carried on by him with unflagging zeal until a few months before his death in 1882, I give in the present paper the measurements made by him in 1881, which he did not live to publish, and those made in 1882 by myself. I shall also endeavour to point out the conclusions which may be drawn from the whole series of observations, beginning in 1878, arranging them under the heads of—

I. ANNUAL OBSERVATIONS.
II. MONTHLY OBSERVATIONS.
III. INFLUENCE OF WEATHER ON THE GROWTH OF WOOD.

Thus the deductions already arrived at by my father in this branch of his investigations on the growth and measurement of trees will be again reviewed and tested by the experience of two additional years. The other branches of his subject, including his inquiry as to the proper mode of measuring the girth of trees, the kind of information to be derived from such measurements, his discussion of DECANDOLLE'S rule for estimating the age of trees by the annual rings, the modes of doing so recommended by himself, and his description of the Fortingall Yew, have been so fully treated in his earlier papers, published in the *Transactions of the Botanical Society of Edinburgh*, as to require little further elucidation. Very different is it however with the yearly and monthly measurements. These can only become truly reliable after a prolonged series of observations; and even the present review of five years' experience must be considered as to a considerable extent provisional and subject to correction.

Before proceeding with the proper subject of this paper, it is advisable to state that the observations and deductions in it rest entirely on the possibility of making accurate measurements of the girth of trees. Previous to Sir ROBERT'S observations measurements of the kind were made in the vaguest and most unreliable manner. It was reserved for him, in extreme but vigorous old age, to make the simple discovery that such measurements could be depended upon to within a tenth or even a twentieth of an inch, and that consequently not only the annual but even the monthly increase could be accurately recorded. I thought it was desirable however on taking up the subject as it dropped from his hands to retest this question, and to ascertain whether my measure-

ments might not, from some difference of manipulation, disagree with his. Accordingly, with the aid of my brother, I remeasured early in 1882 the forty-one trees in the Botanic Garden measured by Sir ROBERT at the end of the growing season in 1881. The result was satisfactory. In nineteen instances there was no appreciable difference between the two measurements; in seventeen the difference did not exceed a twentieth of an inch; in three it amounted to a tenth, and in two to a seventh of an inch. Thus in only five cases were the discrepancies so great as to be of material consequence; and, on investigation, these discrepancies were found to be evidently due either to extreme roughness or a tendency to scale in the bark. So great a degree of accuracy as this however cannot be obtained with ordinary tapes. I have found some of the inches marked on these a tenth of an inch too large, others a tenth too small. Another source of error with them is the terminal ring with the fastenings by which it is attached to the tape. If the measurement be taken over the ring, and it happens to be sunk in a depression of the tree, no error results; but if the ring be on a projection of the bark, its bulk may cause an error in excess amounting to a twentieth or even a tenth of an inch. A different result from either of these will probably be got if the measurement is kept clear of the ring altogether. In the early part of his experiments Sir ROBERT used a tape, painted so as to avoid stretching, and graduated by himself; an extra inch graduated to tenths served for taking the fractions of an inch, so that it was unnecessary to graduate the tape throughout into tenths. But mistakes were apt to arise from the necessity of reckoning the tenths in a direction contrary to the numbering of the inches, and ultimately he used a steel tape, graduated throughout to tenths, made specially for him by Messrs CHESTERMAN. This is certainly the kind most to be recommended.

I. ANNUAL OBSERVATIONS.

Following Sir ROBERT'S example, I give the increments for 1881 and 1882 in a tabular form, along with those already published for previous years. As in the course of time however several of the trees originally selected have ceased to be eligible, I have found it necessary to remodel the table to a considerable extent. Thus the Scots fir, No. 19 in his list, and the *Picea Lowei*, 32, having ceased to grow, have been cut down; the Scots firs, 11, 36, 37, have also ceased to grow for three years; and the yew, 47, is almost in the same predicament. As it was obviously useless to retain these, they have been struck out; and the *Pinus Laricio*, 17, the aged sycamore, 13, and walnut, 14, having bark either so scaly or so rugged as to be unsuitable for minute measurements, have shared the same fate. In compensation for these losses in the Botanic Garden, a larger number of trees growing at Craigiehall, five miles from Edinburgh, have been selected for observation and added to the list. No confusion need be feared from these changes in making comparisons with former years, as the

increments are computed on the average increase per tree in the different classes. For the sake of clearness it has also been judged advisable to divide the table into two parts, the first comprising the twenty-eight deciduous and the second the twenty-three evergreen trees under observation.

I have ascertained that the results obtained from this new list do not differ materially from those derived from the former list by Sir ROBERT. But as it would be useless to cumber these pages with more than one set of observations, I have resolved to give the results of the new list alone, as being both more reliable when corrected so as to apply to the past, and forming a more accurate basis for the future.

TABLE I.—ANNUAL INCREASE IN GIRTH OF DECIDUOUS TREES,

All in the Botanic Garden or Arboretum, except those marked "Craigiehall."

Trees.	Date and Girth when first measured.		Increase.				
			1878.	1879.	1880.	1881.	1882.
		Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Birch, ...	1878	55·35	0·25	0·05	0·05	0·10	0·10
„ (Craigiehall), .	1880	56·30	...	...	0·40	0·55	0·45
Beech, ...	1878	71·40	1·20	0·95	0·65	0·85	1·15
„	„	60·50	1·20	0·80	0·90	0·90	1·10
„	„	75·80	0·60	0·60	0·25	0·50	0·60
„	„	60·30	0·60	0·45	0·15	0·50	0·50
„ (Craigiehall), .	1880	135·00	...	...	0·50	0·65	0·60
„ „ . .	1878	116·35	0·80	0·60	0·40	0·35	0·65
„ „ . .	„	61·75	0·60	0·30	0·50	0·50	0·70
„ „ . .	„	71·85	0·70	0·50	0·55	0·65	0·85
Lime, ...	1878	76·10	0·50	0·15	0·00	0·65	0·55
„	„	42·70	0·70	0·40	0·15	0·25	0.40
„ (Craigiehall), .	„	99·65	0·20	0·15	0·10	0·25	0·35
Sweet chestnut, . .	„	70·80	1·10	0·90	0·85	1·10	0·90
Tulip tree, . . .	„	75·70	1·00	0·40	0·30	0·55	0·50
Horse chestnut, . .	„	48·75	0·75	0·50	0·35	0·70	0·10
Hawthorn, . . .	„	38·00	0·80	0·10	0·75	0·35	0·65
Flowering ash, . .	„	75·30	0·60	0·40	0·30	0·75	0·50
Sycamore, . . .	„	58·60	0·50	0·20	0·15	0·30	0·40
English oak (Craigiehall),	„	69·45	0·65	0·50	0·20	0·35	0·35
Turkey oak, „ .	1880	73·00	...	...	0·70	1·25	0·90
„ „ . .	1878	41·90	0·60	0·65	0·35	0·60	0·65
American oak, . .	„	30·80	0·50	0·40	0·30	0·30	0·40
Hungary oak, . .	„	23·60	1·80	1·70	1·40	1·85	1·85
„ „ . .	1880	16·45	...	...	1·10	1·60	1·90
„ „ . .	„	13·50	...	...	1·10	1·70	1·50
Hornbeam, . . .	1878	44·50	0·40	0·35	0·10	0·55	0·50
Total increase of 22 trees first marked in 1878,	...	...	15·05	11·05	8·75	12·90	13·75
Average per tree,	...	...	0·68	0·50	0·40	0·58	0·62
The same, with 5 added in 1880, . . .	...	...	...	...	12·55	18·65	19·10
Average per tree,	...	...	...	...	0·46	0·69	0·71

TABLE II.—ANNUAL INCREASE IN GIRTH OF EVERGREEN TREES,

All in the Botanic Garden or Arboretum, except those marked "Craigiehall."

Trees.	Date and Girth when first measured.		Increase.				
			1878.	1879.	1880.	1881.	1882.
		Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Douglas pine, . .	1878	56·10	0·60	0·45	0·45	0·60	0·50
" " . .	"	64·30	0·80	0·30	0·35	0·35	0·40
Pinus excelsa, . .	"	30·90	0·35	0·20	0·05	0·30	0·15
" " . .	"	32·70	0·40	0·20	0·35	0·35	0·40
Sequoia gigantea, . .	"	23·95	1·15	0·80	1·00	0·35	0·70
" " . .	"	23·95	1·75	1·65	1·80	1·50	1·40
" " . .	"	18·95	1·85	1·50	1·50	1·30	1·75
" " . .	"	23·85	1·25	1·70	1·55	1·35	1·65
Deodar, . . .	"	26·10	1·10	0·70	0·45	0·35	0·95
" . . .	"	64·00	1·20	0·60	0·40	0·25	0·70
Picea Lowei, . .	"	15·00	1·40	1·25	1·40	0·90	1·05
Araucaria, . . .	"	18·10	0·60	0·50	0·55	0·50	0·45
" . . .	"	20·20	0·50	0·90	0·75	0·60	0·85
" (Craigiehall),	1879	17·90	...	0·85	0·65	0·45	0·70
Atlas cedar, . . .	1878	27·55	1·65	1·40	1·75	1·40	1·60
Evergreen oak, . .	1879	29·05	...	0·40	0·10	0·10	0·25
Yew, ...	1878	67·60	0·60	0·60	0·35	0·50	0·50
"	"	34·10	0·50	0·15	0·20	0·30	0·45
"	1879	37·50	...	0·60	0·40	0·40	0·55
"	"	23·50	...	0·30	0·35	0·45	0·55
"	"	33·30	...	0·45	0·40	0·35	0·45
"	1880	32·35	...	...	0·15	0·15	0·40
Cypress (Craigiehall), .	1879	14·20	...	0·80	1·15	0·85	0·85
Total increase of 16 trees first measured in 1878, . . .	...	...	15·70	12·90	12·90	10·90	13·50
Average per tree,	...	...	0·98	0·80	0·80	0·68	0·84
The same, with 7 added in 1880, . . .	...	...	...	...	16·10	13·65	17·23
Average per tree,	...	...	...	...	0·70	0·59	0·75

The most remarkable result from the whole series of observations is the want of correspondence between the deciduous and evergreen classes in the increase and decrease of the growth of wood in the different years under review. Thus, as the tables show, a remarkable decline took place in both classes in 1879 as compared with 1878, the average growth of each tree for these years in the deciduous class being 0·68 in. and 0·50 in., and in the evergreen class 0·98 in. and 0·80 in. But in 1880, while the deciduous average declined still further,—to 0·40, the evergreens remained quite stationary ;* and in 1881, when

* Sir ROBERT CHRISTISON believed that they also had declined, although to a less extent, but he was misled by an error in the figures of his MS.

the deciduous average rose decidedly,—from 0·40 to 0·58, the evergreens suffered a decided fall,—from 0·80 to 0·68. In 1882 the difference was not so remarkable, as the average of both rose, but in the case of the evergreens to much the greater extent of the two.

I shall endeavour to explain the causes of these differences at the conclusion of this paper, under the head of the connection of weather with the growth of wood.

Sir Robert Christison was inclined to attribute to the oak tribe a greater power of resisting inclement winters than other leaf-shedding trees possessed. At page 84, part iv. of his paper, he states that while leaf-shedding trees in general suffered a reduction of 41 per cent. in their increment in 1879 as compared with 1878, seven oaks measured by him lost only 10 per cent. Unfortunately, for various reasons, all these oaks are not available for comparison in subsequent years, but at page 168, part v., he showed that the average increments of fifteen leaf-shedding trees in three successive years down to 1880 were 0·80 in., 0·45 in., and 0·35 in., and that the corresponding numbers for four of the oak tribe were 0·82 in., 0·77 in., 0·54 in., a result still favourable to the oaks, although not so much so as in the previous instance. But if the facts be examined in detail, it is evident that this apparent superiority of the four members of the oak tribe is really due to one of their number—the hardy and quick-growing Hungary oak —and that the other three, although they suffered little loss in 1879, fell off greatly in 1880. It must be considered also that all these trees, with the exception of the hornbeam, which Sir Robert classed with the oaks, are of foreign origin. If we reckon the growth of the hornbeam with that of the only two British oaks whose measurements are at all reliable, the result is most disastrous for our native oaks; for while their united growth in 1878 was 2·05 in. and in 1879 1·65 in., it was only 0·70 in. in 1880. In these experiments the number of trees may be too small to give thoroughly reliable results, but it certainly seems probable that the foreigners—the Hungary, American, and Turkish oaks—stand severe winters, in our neighbourhood at least, better than our native oaks, the Hungary oak being much the hardiest of all, while the British oak comes out worse than any other species of tree under observation.

The yew seems to form an exception to the rule that the increment of wood in evergreen trees continued to decline in 1881, notwithstanding the remarkable rally made in the leaf-shedding class in that year. We have seen that the average growth of all the evergreen trees declined from 0·80 in. in 1880 to 0·68 in 1881; but if we take the yews alone, five in number, we find that their average growth rose from 0·35 in. in 1880 to 0·40 in 1881. Thus in the wave of decline and rise during the three severe winters they followed the deciduous group, and not their relations the evergreen Pinaceæ.

II. Monthly Observations.

Encouraged by the results of his annual measurements, Sir Robert Christison selected in 1880 five deciduous and six evergreen trees, already ascertained to be quick growers, as suitable for monthly observations. These trees comprised two beeches, three Hungary oaks, four Sequoias, one Araucaria, and an African cedar. They were measured at the end of May, June, July, August, and September. The operation was repeated by himself in the same months, with the exception of May, in 1881; and again by me in 1882, with the exception of August. Thus a tolerably complete record of the monthly increments of these trees was obtained for three seasons. As the number experimented upon, however, was both too limited and comprised too few species to give altogether reliable results, I commenced in 1882 to make monthly measurements of a considerably larger number, and henceforth twenty-eight deciduous and eighteen evergreen trees, including twenty-two species, will be under observation.

I shall now proceed to consider the conclusions to be derived from these measurements in the solution of the following questions:—1. *What are the months to which the growth of wood is confined* (a) *in deciduous trees as a class and* (b) *in evergreens as a class?* 2. *In which month is the growth of wood most active in these two classes* (a *and* b) *respectively?* 3. *What are the peculiarities in these respects of different species of trees?*

In the Tables III., IV., and V. the facts will be found in detail on which the subsequent conclusions are founded. Table III. gives the three years' measurements and average growths of the smaller number of trees originally selected by Sir Robert; Tables IV. and V. the results of a single year's observations on the larger number, measured for the first time in 1882. The trees in this list only partially correspond with those used for annual observations, as a considerable number of the latter, from growing too slowly or from other causes, are not reliable for minute measurements.

1, a. *The Months to which the Growth of Wood is confined in Deciduous Trees.*

From the measurements made in 1880 on his five selected trees, Sir Robert came to the conclusion that the growth of wood in leaf-shedding trees is confined in general to the months of June, July, and August. I think however that he underrrated the importance of the May growth. It amounted to 12 per cent. of the annual total, which it must be admitted is a substantial sum. It was due however almost entirely to the three Hungary oaks, the increase in the two beeches having been scarcely appreciable. Unfortunately the measurements for 1881 were not taken till the end of June, so they are not available for this inquiry. But after the unusually mild winter of 1882 the May growth

was nearly twice as great as in 1880, amounting to 21 per cent. of the annual increase. Again no doubt it was mainly due to the Hungary oaks, their proportionate growth for May having been 24 per cent. of their annual increase; still the beeches were not idle, their corresponding growth amounting to 10 per cent. And although the Hungary oak—exceptional among deciduous

TABLE III.—MONTHLY INCREASE IN GIRTH, IN HUNDREDTHS OF AN INCH, OF FIVE DECIDUOUS AND SIX EVERGREEN TREES IN THE BOTANIC GARDEN.

	1880.						1881.				1882.				
	May.	June.	May and June.	July.	Aug.	Sept.	May and June.	July.	Aug.	Sept.	May.	June	May and June.	July.	Aug. and Sept.
Deciduous Trees—															
Beech, .	·00	+ ·25	= ·25	·50	·10	·00	·20	·25	·35	·05	·10	+ ·35	= ·45	·40	·30
„ . .	·10	+ ·30	= ·40	·20	·35	·05	·35	·35	·15	·05	·15	+ ·30	= ·45	·30	·35
Hungary oak,	·30	+ ·40	= ·70	·40	·30	·00	·60	·50	·65	·05	·30	+ ·45	= ·75	·60	·50
„ „	·05	+ ·40	= ·45	·30	·30	·05	·65	·45	·50	·00	·35	+ ·50	= ·85	·55	·50
„ „	·20	+ ·30	= ·50	·30	·25	·05	·60	·55	·50	·00	·65	+ ·15	= ·80	·50	·20
Total, .	0·65	+ 1·65	= 2·30	1·70	1·30	0·15	2·40	2·10	2·15	0·15	1·55	+ 1·753	= ·30	2·35	1·85
Average per tree, . .	0·13	+ 0·33	= 0·46	0·34	0·26	0·03	0·48	0·42	0·43	0·03	0·31	+ 0·35	= 0·66	0·47	0·37
Monthly percentage, .	12	+ 30	= 42	31	24	3	35	31	32	2	21	+ 23	= 44	31	25
Evergreen Trees—															
Sequoia, .	·40	+ ·25	= ·65	·40	·05	·00	·40	·00	·15	·00	·25	+ ·30	= ·55	·10	·05
„ .	·55	+ ·50	= 1·05	·70	·15	·00	1·00	·05	·45	·00	·45	+ ·65	= 1·10	·20	·10
„ .	·70	+ ·40	= 1·10	·30	·00	·00	·85	·25	·20	·00	·75	+ ·65	= 1·40	·25	·10
„ .	·55	+ ·40	= ·95	·45	·00	·00	·75	·30	·30	·00	·55	+ ·55	= 1·10	·40	·15
Araucaria, .	·40	+ ·15	= ·55	·15	·05	·00	·35	·10	·15	·00	·45	+ ·10	= ·55	·15	·15
Atlas cedar, .	·45	+ ·30	= ·75	·40	·50	·05	·55	·35	·50	·00	·35	+ ·40	= ·75	·40	·45
Total, .	3·05	+ 2·00	= 5·05	2·40	0·75	0·05	3·90	1·05	1·75	0·00	2·80	+ 2·65	= 5·45	1·50	1·00
Average per tree, . .	0·51	+ 0·33	= 0·64	0·40	0·12	0·01	0·48	0·17	0·29	0·00	0·46	+ 0·44	= 0·90	0·25	0·17
Monthly percentage, .	37	+ 24	= 61	30	9	0	51	18	31	0	35	+ 33	= 68	19	13

trees for its early vigour—unduly raises the average in so small a number of trees, a substantial increase in May nevertheless did take place among deciduous trees in general. For if we include the whole of them, twenty-five in number, other than Hungary oaks, which were measured for the purposes of this inquiry for the first time in this same year, their average growth in May proves to be 12 per cent. of the annual increase. Including the three Hungary oaks the proportion amounted to 16 per cent.

At the conclusion of the growing season the limit is probably more fixed. Neither in 1880 nor in 1881 was a greater increase than a twentieth of an inch recorded in any tree in September. So small an amount as this comes within

TABLE IV.—MONTHLY INCREASE IN GIRTH OF TWENTY-EIGHT LEAF-SHEDDING TREES IN THE BOTANIC GARDEN, ARBORETUM, AND AT CRAIGIEHALL IN 1882.

No.	Trees.	Girth 31st March.	Increments in hundredths of an inch.			
			May.	June.	July.	August.
7	Beech,	75·05	·10	·35	·40	·30
8	„	64·30	·15	·30	·30	·35
14	„	77·85	·05	·20	·20	·15
38	„	62·00	·00	·15	·30	·05
8	„ Craigiehall,	136·15	·00	...	·25	·15
9	„ „	118·45	·10	·15	·25	·15
14	„ „	63·70	·15	·10	·25	·20
15	„ „	74·30	·15	·20	·30	·20
22	„ „	98·35	·10	·10	·20	·05
40	Hungary oak,	30·35	·30	·45	·60	·50
54	„ „	19·15	·35	·50	·55	·50
55	„ „	16·30	·65	·12	·50	·20
44	American oak,	32·55	·15	·10	·15	·00
43	Turkish oak,	44·20	·10	·15	·30	·15
10	„ „ Craigiehall,	74·95	·20	·20	·30	·20
12	English oak,	71·15	·05	·05	·10	·15
33	Hornbeam,	45·90	·15	·15	·15	·05
28	Sycamore,	59·75	·00	·25	·15	·05
58	„	63·50	·00	·05	·05	·00
7	„ Craigiehall,	127·75	·00	·25	·15	·05
18	Lime,	44·20	·05	·15	·20	·00
21	„ Craigiehall,	100·35	·00	·05	·15	·25
3	Ash,	77·35	·20	·15	·15	·00
6	„ Craigiehall,	141·40	·10	15	·05	·05
4	Spanish chestnut,	74·75	·05	·20	·30	·35
9	Horse chestnut,	51·05	·00	·05	·05	·00
6	Tulip tree,	78·15	·00	·05	·20	·25
5	Birch, Craigiehall,	57·15	·00	·15	·20	·10
	Average of the 28 trees,	...	·11	·18	·24	·16
	„ 3 Hungary oaks,	...	·43	·37	·53	·40
	„ 25 others,	...	·07	·15	·20	·13
	„ 9 Beeches,	...	·09	·19	·27	·18
	Monthly percentage of 28 trees,	...	16	26	35	23
	„ „ 3 Hungary oaks,	...	25	20	31	24
	„ „ 25 others,	...	13	27	36	24
	„ „ 9 Beeches,	...	12	26	37	25

the limit of probable error ; it may be doubted, therefore, whether any increase really took place in that month ; but as the differences between the records of

August and September, trifling though they were, all indicated an increase, it is probable that a slight and altogether immaterial growth did occur. Measurements kindly made for me by Mr SADLER in 1882 to test this question further

TABLE V.—MONTHLY INCREASE IN GIRTH OF EIGHTEEN EVERGREEN TREES IN THE BOTANIC GARDEN, ARBORETUM, AND AT CRAIGIEHALL IN 1882.

No.	Trees.	Girth 31st March.	Increments in hundredths of an inch.			
			May.	June.	July.	August.
		Inches.				
25	Sequoia,	27·55	·25	·30	·10	·05
27	„	30·65	·45	·65	·20	·10
1	„	25·10	·75	·65	·25	·10
2	„	29·70	·55	·55	·40	·15
29	Deodar,	28·70	·10	·20	·30	·35
30	„	66·45	·00	·20	·30	·20
34	Araucaria,	20·25	·25	·10	·05	·05
35	„	22·95	·45	·10	·15	·15
4	„ Craigiehall,	19·85	·25	·25	·10	·10
31	Picea Lowei,	19·95	·45	·20	·20	·20
5	Douglas pine,	58·20	·15	·25	·10	05
2	Austrian pine, Craigiehall,	21·55	·65	·40	·20	·30
39	African cedar	33·75	·35	·40	·40	·45
1	Cypress, Craigiehall,	17·00	·35	·25	·20	·05
41	Yew,	69·65	·10	·15	·10	·15
48	„	38·90	·15	·15	·20	·05
49	„	24·60	·20	·10	·15	·10
53	„	32·50	·20	·00	·05	·15
	Average of 18 trees,	...	·31	·27	·19	·15
	4 Sequoias,	...	·50	·53	·24	·10
	3 Araucarias,	...	·31	·15	·10	·10
	4 Yews,	...	·16	·10	·12	·11
	2 Deodars,	...	·05	·20	·30	·27
	Monthly percentage of 18 trees,	...	34	29	21	16
	4 Sequoias,	...	36	39	28	7
	3 Araucarias,	...	47	23	15	15
	4 Yews,	...	33	20	25	22
	2 Deodars,	...	6	24	37	35

proved unfortunately unavailable, owing to inaccuracies in the tape used. But as the increment for August and September combined was less than in the two previous years, it is fair to conclude that there could have been no material growth in the latter month.

1, b. *The Months to which Growth of Wood is confined in Evergreen Trees.*

From the monthly measurements in 1880 of the six originally selected trees, Sir ROBERT concluded that the evergreen class begins to increase materially in girth

in May, a month earlier than leaf-shedding trees. This conclusion is amply confirmed by the measurements of the two succeeding years. In 1881, indeed, the proof is not positive, as the first measurements did not take place till the end of June; but as 51 per cent. of the whole annual growth was accomplished by that date, it is fair to conclude that a considerable proportion of the increase must have taken place in May. In 1882 there is no room for doubt. The increment till the end of that month actually exceeded the increment of any other month, and the only question is whether a portion of that remarkable growth was not due to April. Unfortunately, as no measurements were taken at the end of that month, this point must remain doubtful.

But the reliability of results obtained from so limited a number of trees and species may justly be questioned. At all events, it may be held that, although true of these species, they may not be true of evergreens in general. Fortunately, however, these results are amply corroborated by observations on the larger number of evergreen trees, first measured for monthly comparison in 1882. The proportion of annual increment in these eighteen trees due to May was 34 per cent., almost identical with that of the selected six, which was 35 per cent.

The limit of the growing season in evergreen trees is better ascertained at the end than at the beginning. Of the six selected trees only one—the African cedar—showed the slightest trace of increase in September, and that only in one of the two years in which observations are available. The increment recorded, moreover, was so slight as to come within the limit of probable error.

In August the proportionate growth seems to be much less in evergreen than in deciduous trees. In August 1880 the increment of the six selected evergreen trees was only 9 per cent. of the annual increase, while in the deciduous group it was 27 per cent. In 1881 there was a greater equality, the respective percentages being 31 and 34. But in 1882 that of the evergreens again fell to 13, while the deciduous percentage reached 25. The results for the latter year were confirmed by the observations on the larger number of eighteen evergreen trees, whose proportionate growth for August was only 15 per cent. of the annual increase.

On the whole, the conclusions to be drawn from all these observations are—*First*, that in ordinary seasons the growth of wood in deciduous trees is mainly confined to June, July, and August. In September it is scarcely appreciable. In May however a small growth does take place, which in favourable seasons may become of no insignificant amount. The Hungary oak not only grows with exceptional vigour in May, but probably in favourable seasons makes a start in April. *Secondly*, that evergreen trees as a class begin to grow probably a month earlier than the deciduous group. They make substantial progress in May, and some of them perhaps make a start in April. On the other

hand, the measurements indicate that they stop growing somewhat earlier than the deciduous class.

Thus Sir ROBERT CHRISTISON'S conclusions are substantially confirmed, although the growth of deciduous wood in May is probably of somewhat greater importance than he supposed. It must be remembered, however, that these rules apply only to the neighbourhood of Edinburgh. In the milder climate, aided by a richer soil, of the south-western districts of Britain, where the leaves expand two or three weeks earlier than here, it is to be expected that the growth of wood will also be correspondingly earlier. Other leaf-shedding species besides the Hungary oak may also be found to be exceptional in the early vigour of their growth, as Sir ROBERT'S observations and my own include but a small proportion of the numerous native and foreign trees which thrive in our islands.

A greater irregularity in the distribution of the monthly growth of the evergreens as compared with the deciduous trees occurred in all the three years during which monthly measurements were made. Thus, while the July percentages of growth in deciduous trees as shown in Table III., were 31, 31, and 31 in these three years, in the evergreen group they were 30, 18, and 19. In August the differences were still more striking, the respective figures being 24, 32, 25 for the deciduous group, and 9, 31, 13 for the evergreen.

It is remarkable that in 1881 the growth of the six evergreens, which in July amounted to only 18 per cent. of the annual increment, became vigorous again in August, when it reached 31 per cent. The deciduous group seemed to partake in this exceptionally vigorous growth in August 1881, but to a much less degree, the proportions being 31 per cent. for July and 34 per cent. for August. In treating of the influence of weather on the growth of wood I shall endeavour to explain these apparent anomalies.

2, a. *The Months in which the Growth of Wood is most active in Deciduous Trees.*

TABLE VI.—MONTHLY PERCENTAGES OF INCREASE IN GIRTH OF DECIDUOUS TREES.

	May.	June.	May and June.	July.	August	Sept.
5 Selected deciduous trees, 1880, .	12	+ 30	= 42	31	24	3
" " 1881, .	...	...	35	31	32	2
" " 1882, .	21	+ 23	= 44	31	25	...
28 Deciduous trees, 1882, . .	16	+ 26	= 42	35	23	...

To elucidate this subject I give in Table VI. the percentage of growth due to each month of the years 1880, 1881, and 1882, in the five originally selected

deciduous trees, and the corresponding results for the growing months of 1882 in the larger number of trees then under observation.

The Table shows that in 1880 June and July were the best growing months for the five selected trees. The amount in these two months was nearly equal. The united growth of August and September, of which September's share was very trifling, was not much less than that of June or July, while that of May was only half that of August.

The year 1881 is not fully available for this inquiry, no measurements having been taken for May; but as the united growth of May and June but little exceeded that of July or August, it is fair to conclude that the increase in June alone was less than in either of the subsequent months.

In 1882 the growth of the five trees in question was apparently distributed over a longer period. May takes a more prominent place with 21 per cent. The growth for June and combined August and September is not much greater, while July takes a decided lead with 31. The preponderance of the early-growing Hungary oak in the small number of selected trees, however, gives a false impression of the increased deciduous growth in May of this year. If we consider the whole number of deciduons trees, twenty-eight in all, under observation in 1882, the percentage for May is reduced to 16, which is still, no doubt, a substantial and probably an unusual amount.

2, b. *The Months in which the Growth of Wood is most active in Evergreen Trees.*

TABLE VII.—MONTHLY PERCENTAGE OF INCREASE IN GIRTH OF EVERGREEN TREES.

	May.		June.		May and June.	July.	August.
6 Selected evergreen trees, 1880,	37	+	24	=	61	30	9
" " 1881,	...		...		51	18	31
" " 1882,	35	+	33	=	68	19	13
18 Evergreen trees, 1882, . .	34	+	29	=	63	21	16

It is more difficult to determine from the available data the month of greatest growth in evergreen than in deciduous trees. Not only are the variations in this respect in different years greater in the former than the latter, but it is doubtful whether a part of the increment attributed to May ought not to be credited to April in the case of evergreen trees. This doubt arises from Sir ROBERT having concluded, probably too hastily, that no growth takes place in April. I can find no evidence in his papers of his having ascertained this by measurement, and I do not know how he came to form and act upon that conclusion. Further observations are evidently necessary to settle this doubt, and

these I hope to undertake in future years.* At present all that we can safely say is that the increase of wood in evergreen trees from the beginning of spring till the end of May probably exceeds on an average that of every subsequent month. Table VII. shows that it did so in the case of the six selected trees in 1880 and 1882, also in the eighteen trees measured in the latter year. In 1881 the observations are incomplete, as separate measurements were not made for May and June, but August—with 31 per cent.—has a strong claim to the highest place, due I believe to exceptional circumstances.

One of the most remarkable conclusions that may be drawn from the three years' monthly observations on evergreen trees, as a class, is that they apparently accomplish the greater part, and sometimes much the greater part, of their growth by the end of June. Thus in 1880, 64 per cent., in 1881, 51 per cent., and in 1882, 68 per cent. of the annual increment of the six selected trees was finished by that date, and the increment of the eighteen trees measured in 1882 was almost identical with that of the six in the same period, amounting to 63 per cent. Apparently then it is not heat alone which regulates the growth of wood in many evergreen trees. By some inherent vital power they complete the greater part of their growth before the commencement of the two warmest months in the four which constitute the growing period, or else their vital power is so exhausted in the early part of the season that growth cannot be carried on with vigour when the real heat of summer comes on.

In conclusion, it must be allowed that further observations, both on deciduous and evergreen trees, are required to determine which is the best growing month in each class. At present the indications are in favour of July for the former and May for the latter, if the whole, or nearly the whole, of the growth hitherto ascribed to that month really belongs to it.*

3. *Monthly Increase in certain Species of Trees.*

There is considerable variety in the vigour of growth in different species both of deciduous and evergreen trees in the different months of the growing season. My observations on this point indeed, on any considerable number of trees, extend only to a single year, but the results are sufficiently striking to deserve attention. In Table VIII. are given the percentages of monthly growth in seven species, which, either from the number of specimens under observation, or from the certainty of their measurement, yield the most reliable results.

The Hungary oak begins to grow earlier than any other of the deciduous trees under observation. In the backward spring of 1880 the three specimens marked in the Botanic Garden were well clothed with foliage on the 15th May,

* Since this paper was read, the spring measurements for 1883 show a growth in April amounting to two-fifths of that in May in twenty evergreens under observation. It appears probable therefore that June is the month of greatest growth for evergreens.

and after the wonderfully mild winter of 1882 one of them was beginning to expand its leaves on the 27th of March. Their growth was more evenly distributed over the four growing months than that of any others of the deciduous group, and among the evergreens the yews alone rivalled it in that respect. The Turkish and American oaks seem also to be early growers. The proportion of their May growth was not much less than that of the Hungary oaks, still in both the first and last months of the growing season they were less active than the latter. The British oak grows poorly in this district, and besides, from the roughness of its bark, it is not suitable for minute measurements. The only one experimented upon showed no appreciable increment in May.

The beeches made only 12 per cent. of their annual increment in May, about half the proportion of the foreign oaks, and as this was in an unusually early season it is probable that in ordinary years their May growth must be very trifling.

TABLE VIII.—MONTHLY PERCENTAGE OF INCREASE IN GIRTH OF SEVEN SPECIES OF TREES IN 1882.

	Till 31st May.	June.	July.	August.
3 Hungary oaks,	25	21	31	23
2 Turkish and 1 American oak,	22	22	38	18
9 Beeches,	12	26	37	25
4 Sequoias,	36	39	18	7
3 Araucarias,	48	22	15	15
2 Deodars,	6	24	37	33
4 Yews,	33	20	25	22

Among other deciduous species, which being less reliable do not find a place in this Table, the ash and the hornbeam alone showed an appreciable growth in May. It is fair to state however, that in the Edinburgh district the horse chestnut leaves were almost universally destroyed in 1882 by early frost and the ravages of insects. It is no wonder therefore that the specimen measured in the Botanic Garden grew only a tenth of an inch in the year.

The Sequoias were remarkable, even among evergreens, for the early vigour of their growth. No less than 75 per cent. of their annual growth was finished by the end of June. But they ceased to increase earlier than any of the other species, their growth in August being only 7 per cent.

The Araucarias also grew rapidly in the early part of the season, accomplishing very nearly one half of their annual increment by the end of May, and 70 per cent. by the end of June.

With the Deodars it was exactly the reverse, 70 per cent. of their increment taking place after June. If the observations for a single year on two trees may be trusted, the Deodar is an exception to the general rule of early growth in evergreens

The increase of the yews was nearly equally divided between the first and second periods of the season. The former had indeed a slight advantage, but the spring of 1882 was unusually early, and a longer experience may show that yews do not follow the rule of early growth which appears to hold good in most of the Pinaceæ.

As it may be of some interest to show the comparative rate of growth of wood in certain species of trees under observation, I give the following Table:—

TABLE IX.—AVERAGE INCREASE IN GIRTH OF EIGHT SPECIES OF TREES FOR THREE YEARS.

	1880.	1881.	1882.	Average.
Average of—	Inch.	Inch.	Inch.	Inch.
3 Hungary oaks,	1·20	1·72	1·75	1·55
1 American and 2 Turkish oaks,	0·45	0·75	0·65	0·62
9 Beeches,	0·53	0·64	0·79	0·65
4 Sequoias,	1·46	1·17	1·40	1·01
3 Araucarias,	0·65	0·51	0·66	0·61
2 Deodars,	0·42	0·30	0·82	0·51
4 Yews,	0·31	0·37	0·50	0·39
1 African cedar,	1·75	1·40	1·60	1·58

III. INFLUENCE OF WEATHER ON THE GROWTH OF WOOD.

This is a complicated inquiry, so many and various are the influences which may come into play. Extreme frost, prolonged frost, the amount of heat and sunshine, drought or excessive rain, strong winds, all no doubt affect the growth of wood, their influence varying with the seasons, and not necessarily showing their effects immediately.

Of all these agents cold is probably the most energetic; I have therefore looked to it mainly for explanation of the differences in annual growth, adopting Mr SADLER'S record of temperature in the Botanic Garden as my guide, because the greater number of the measured trees are situated either there or in the adjoining Arboretum. The thermometers used by him are four feet from the ground, and being unprotected the readings are not strictly accurate, but for purposes of comparison with each other the observations are sufficient.

Sir ROBERT CHRISTISON showed that the remarkable cold and absence of sunshine in the spring and summer of 1879 caused a great deficiency in the growth of wood, both in deciduous and evergreen trees, in that year as compared with the previous one; that the deficiency was greatest in the deciduous class; and least of all, so far as his observations went, in oaks.

In 1880 the spring was favourable to the opening buds, the temperature

being considerably above average in February and March, while although April was cool it was free from severe frosts. The summer was also of an average character. The foliage was therefore, in general, rich and abundant. Nevertheless there was again a great falling off in the growth of deciduous wood. This Sir ROBERT attributed to the extraordinary low temperatures of the previous December, succeeding an autumn unfavourable to the ripening of wood and formation of buds. He believed that evergreen trees had also suffered, although not to the same extent; but I find that he had been deceived by an error in copying his figures, and that their growth in 1880 was almost identical with that of 1879.

It is not easy to explain why both classes should have suffered a diminution in the growth of wood in 1879, and only the deciduous class a further decline in 1880. In the first of these years the cause of deficiency was no doubt, as Sir ROBERT believed, the inclement spring and summer, as the cold of the previous winter although prolonged was not remarkably intense; under these circumstances both classes of trees were unfavourably influenced. In 1880 on the other hand the cold of the previous winter was both prolonged and intense, and in all parts of the country its effects were visible in the killing of tender young wood or even of whole trees. It is no wonder then that the deciduous trees showed a marked decline in addition to the serious loss they had suffered in the previous year. But why did the evergreen class escape this further loss? Possibly the explanation of this difference may be found in the earlier activity of growth in evergreens in spring. In their exposure to the intense frost of winter their circumstances must have been much the same as those of the deciduous class, but their comparatively early buds would probably come under the influence of the genial March and April to a greater degree than the later buds of the leaf-shedding trees, which, on the other hand, would encounter a rather inclement May. Another cause that may be suggested is that the previous autumn, which was highly unfavourable to the ripening of wood, may have in some way prejudiced the evergreens less than the deciduous trees. That the evergreen trees under observation were not really hardier than the deciduous ones was proved by their fate in the following year.

The winter of 1880–81 was even more protracted and severe than that of 1879–80. Both the lowness of the average temperature and the number of extremely low readings at the Botanic Garden in January, the coldest month of 1880–81, were more remarkable than in December, the coldest month of the previous winter. Thus the lowest temperatures recorded in the latter month were 1°, 4°, 15°, 17°, 19°, but those of January 1881 were 0°, 4°, 7°, 10°, 11°, 12°, 12°, 12°, 13°, 14°. And this greater cold was prolonged far into the spring. On the last day of February and first few days of March 15°, 15°, 18°, and 19° were recorded,

and another wave of cold brought the thermometer below the freezing point on twelve nights in the first fortnight of April, the lowest readings being 21°, 22°, and 23°. On the other hand, the lowest readings in the same months of 1880 were only 23° in February, 22° in March, and 27° in April. Moreover, the total number of nights of frost in these three months in 1880 was only thirty-four, while in the corresponding period of 1881 it was fifty-three.

After so severe a winter and spring it might have been expected that even more disastrous effects on the growth of wood would have resulted than after the less extreme cold of the previous year. But, on the contrary, the deciduous trees, at least, made a remarkable rally, the average growth of twenty-seven of them having risen from 0·46 in. in 1880 to 0·69 in. in 1881, an increase of nearly one-third. Very different however was the fate of the evergreen trees. Unlike the deciduous class they had successfully resisted the efforts of the previous hard winter, but now they suffered seriously, thus differing once more from the leaf-shedding trees, but in the opposite way, for their average growth, which in 1880 had been 0·70 in., was now only 0·59 in.

The wonderful rally made by the leaf-shedding trees in 1881, notwithstanding the almost unprecedentedly low temperatures of the previous winter, can only be accounted for, I believe, by the favourable character of the preceding autumn, which allowed the growth of wood of 1880 to be perfectly matured, and so enabled it to withstand the rigour of the winter in 1881. But why was a similar effect not produced upon the evergreens? Is it because the maturing of wood is not so effectual with them as it appears to be with the deciduous trees in enabling them to resist a severe winter? Or shall we find the reason in the comparatively early growth of evergreens which might expose their tender buds to the frequent low temperatures of March and April, a danger from which the buds of the deciduous class, coming out later, would be free, while they would benefit by the geniality of May? The latter seems the most probable cause, but further observations are required to settle the question.

The winter of 1881–82 was one of the mildest on record. It was well suited therefore to test Sir ROBERT'S suggestion that evergreens might in an unusually mild winter show some trace of growth; but none could be detected in any of the twenty-eight measured trees. Vegetation however was very early. A sycamore and a Hungary oak among the marked trees in the Botanic Garden began to expand their leaves on the 27th of March. The sycamore paid dearly for its temerity. Caught by an early frost and afterwards attacked by insects, its leaves were irretrievably injured, and its increase in girth for the year only amounted to a twentieth of an inch. A similar fate befell nearly all the horse chestnuts near Edinburgh, including a fine specimen, one of my measured trees, which grew only a tenth of an inch in the year. The Hungary oak, on the other hand, did not suffer at all. The deciduous class as a whole,

however, were not injured in this way; but notwithstanding the mild winter they only maintained their improvement of the previous year, without attaining the standard of growth of 1878. The reason of this failure, no doubt, was the unfavourable nature of the previous autumn for the ripening of wood, combined with the ungenial nature of the growing season, both of which were well-marked evils at the Botanic Garden, as I was informed by the late lamented Mr SADLER shortly before his death.

The evergreens, on the other hand, recovered their loss of the previous year. Apparently the frost of April had not injured them, and they had been stimulated by the mildness of May, as their growth till the end of that month bore a high proportion to the whole annual increase.

This attempt to connect the annual variations in the increase of wood with temperature, and to explain the curious contrasts between deciduous and evergreen trees in their annual growth by the effects of temperature alone, cannot be considered as altogether satisfactory. Neither are the difficulties cleared up by considering other causes which must manifestly affect the growth of wood. Violent winds, for example, must be prejudicial not only by tearing down important branches, but by damaging the leaves. Every one must have observed the injury done to foliage by storms, particularly in spring and the beginning of summer. Multitudes of leaves are blown away, and those which remain hang limp and shrivelled from the branches, their petioles twisted by the wind, and the circulation through them thus hindered by bruising of the vessels. In the records of the Scottish Meteorological Society many gales are reported as having occurred at Edinburgh in the years with which we have to do, but I cannot clearly trace a connection between them and any diminution in the growth of wood. I should have expected the greatest damage to have been done in 1881. In the previous year, indeed, there were three gales in May, but it was a backward spring, and the leaves may thus have escaped. At all events we know that Sir ROBERT remarked the richness and abundance of foliage in June, and there were no gales in that or the subsequent growing months. In 1881, on the other hand, one gale in May, three in June, two in July, and four in August were recorded; yet this was the year in which, with all the disadvantage of a previous winter of almost unprecedented severity, the growth of deciduous wood made a remarkable rally. But the fact is that the effects of each gale must be watched in order to know whether any general damage has been done to the leaves or not, so much depends on the strength of the wind, its direction, and the shelter which may protect the trees concerned. I should expect that differences between the annual increase of deciduous and evergreen trees might sometimes be due to this cause, as the leaves of the latter, from their shape, cannot be exposed to

the same injury as those of the former; but in the years now under consideration I cannot trace any such effect.

In a climate such as ours, with frequent variations from the average in the monthly rainfall, considerable effects on the growth of wood may be expected from excess or deficiency of rain at the growing season. To trace these effects may be difficult, from the possible simultaneous action of other causes immediate or remote; nevertheless I think something may be made of an examination of the principal abnormalities in the rainfall during the three years in which monthly observations of growth were taken. I owe to the kindness of Mr BUCHAN the following Table, showing the excess or deficiency of rain during the months of the period in question. The means from which these are calculated are derived from twenty-eight years' observations at Charlotte Square, whereas the monthly rainfall is taken from observations at Cumin Place, Grange; but the general results are not likely to be seriously affected by this difference.

TABLE X.—MONTHLY EXCESS OR DEFECT OF RAIN AT EDINBURGH IN 1880, 1881, AND 1882.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1880, .	-1·69	+0·03	-0·09	+0·11	-1·05	-0·46	+1·91	-2·46	+0·17	+1·66	+1·54	+1·01
1881, .	-0·70	+2·81	+0·13	-0·32	-0·04	-0·61	+0·52	+3·06	+0·97	-0·50	+0·60	-0·83
1882, .	-0·55	+0·01	+1·04	+1·00	+0·29	+0·28	-0·51	-0·85	...	...	...	...

In comparing the rainfall with the tree-growth, I shall make use of the proportion which the monthly percentage of the latter bears to the whole annual growth. These will be found in Table VI. and VII.

1880.—The rainfall of May was less than half the average, and that of June was deficient by about a third; but the increase of wood in both classes of trees was quite up to the average of the same period for three years. In July the rainfall was much in excess: the deciduous growth was an average one; but the evergreen growth was much above the average. In August there was a great deficiency of rain, — 2·46, and an excess of heat, + 3°·3; the deciduous growth was about an average, the evergreen greatly below average.

1881.—In April, May, and June there was a deficiency of rain, but it only amounted to an inch in all, and as vegetation was completely checked by severe weather till the middle of April, the small proportionate growth of both classes of trees in May and June may fairly be attributed to the latter cause. In July the rainfall was slightly in excess: the deciduous growth was again an average, but the evergreen under average. In August, the memorable month of the Volunteer Review at Holyrood Park, no less than 6 inches of rain, double the

average, fell at Edinburgh: then the evergreens made a surprising rush, no less than 31 per cent. of their annual growth taking place, whereas in August 1880 the portion was only 9 per cent., and in 1882, 13 per cent. This result was the more remarkable, as the temperature of the month was 2°·3 below the average. The deciduous trees were also apparently benefited by this excessive rain, although accompanied by deficient temperature, their proportion being 34 per cent. in August and September of 1881, while it was only 27 per cent. in 1880, and 25 per cent. in 1882.

1882.—The rainfall of March, April, May and June was abundant, exceeding the average by an inch in each of the first two months, and being rather above the average in the third and fourth. In the same period the growth of evergreen wood was large, but this may easily be accounted for by the mild winter and early spring, without calling in the aid of the rainfall.

Taking a general view of this investigation, it appears as if an abundant rainfall were favourable to the growth of wood, but much more favourable to the evergreen than the deciduous class. It must be admitted however that a longer series of observations, taken on a larger scale, are necessary to determine this point. The most striking fact shown is the extraordinary increased growth of the evergreens in August 1882, along with a very heavy rainfall and low temperature, whereas in the previous August, when the conditions were reversed, the rainfall being 2·46 inches in default and the temperature 3°·3 in excess, the evergreen growth was very deficient.

Summary.

To give a better idea of the general scope of this paper, the details of which are necessarily of a somewhat dry and tedious character, I now give a summary of the chief conclusions which are scattered throughout the text. It must be remembered however that these conclusions are strictly applicable only in the Edinburgh district, and that some of them are only indications of the probable truth, and require to be confirmed by a larger series of observations.

1. The effects upon the growth of wood of the severe winters preceding the growing seasons of 1879, 1880, 1881 were not the same in deciduous and evergreen trees. In 1879 both suffered: the former more than the latter. In 1880 a further decline took place in the deciduous class, but not in the other. In 1881 the deciduous class recovered their loss of the previous year, but it was now the evergreen's turn to fall off. After the unprecedentedly mild winter of 1882 they again differed. For while the deciduous trees made no further recovery, the evergreens regained the loss sustained in 1881; neither class however attaining to the standard of growth in the favourable season of 1878.

2. Evergreen trees probably do not increase their wood at all in winter,

however mild it may be, as not the slightest trace of growth could be detected in the measured trees after the wonderfully mild winter of 1882.

3. The British oak probably suffered a greater decline in its growth of wood from the severe winters than any other tree under observation. The Hungary oak, on the other hand, was less affected than any other tree; and the Turkish and American oaks less than our native oak.

4. In the wave of increase and decrease in wood growth through these years the yews followed the deciduous class, and not their congeners the evergreen pines.

5. The appreciable growth of wood in deciduous trees is mainly confined to June, July, and August in ordinary seasons; but a material increase does take place in May, particularly when the spring is unusually mild.

6. The growing season in evergreen trees includes May, and probably an appreciable start is made even in April, when the spring is favourable.

7. The proportionate monthly growth seems to vary more in evergreens than in deciduous trees.

8. The growth of wood is probably greatest in July in deciduous trees, and in June* in evergreens; but further observations are required to settle these points.

9. On an average of three years the evergreen trees as a class accomplished 60 per cent. of their annual increase of wood before the end of June, the deciduous 60 per cent. of theirs after that date. Deodars appear to be exceptional, as they agreed with the latter instead of the former group. In yews the growth is probably pretty equally divided between the two periods.

10. Of all the species measured, the Hungary oak and African cedar proved much the quickest growers. Then followed the *Sequoia gigantea*.

11. Thorough ripening of wood in autumn seems to be of immense consequence in enabling deciduous trees to stand extremely low temperature in winter. Evergreens however do not seem to be so dependent on it.

12. An excessive rainfall seems to be favourable to the increase of wood, particularly in evergreen trees. A great excess of rain in August 1881 apparently stimulated the growth of wood in these to a remarkable degree, although the temperature of the month was decidedly low.

In conclusion, I cannot help expressing a wish that others who have better opportunities than I can command would take up a line of inquiry which Sir Robert Christison has made easy by the practical rules he has laid down for its prosecution. The necessary observations are not difficult to make, merely requiring precision; and they take up little time when the trees experimented upon are near at hand. The work is interesting, and the results may prove to

* See foot note, page 57.

be of importance in unexpected ways. I must also repeat the surprise which Sir ROBERT often expressed, that little or nothing seems to have been done to ascertain the effects of manuring on tree growth. "Mulches" have indeed been applied to favourite trees when in a sickly state, and often with the best results, but the farther step of trying the effect of manures in stimulating the growth of healthy trees has not, so far as I am aware, been taken. Perhaps the want of any reliable method of ascertaining the rate of growth of wood has hitherto stood in the way of such experiments ; but surely there is the greatest encouragement to undertake them, now that Sir ROBERT has shown the ease and accuracy with which minute measurements of the girth of trees can be made, and their rate of growth thus ascertained in comparatively short periods of time. If such application of manures proved useful, but at the same time too expensive to be employed on the great scale, it should at least be welcomed by the landed proprietor to secure a more rapid growth of young ornamental wood.

Note.—In Table III. the average growth of the Evergreen trees for May and June 1881 should be 0·65 instead of 0·48, and the monthly percentages 59, 15, 26, instead of 51, 18, 31. The latter errors occur also in Table VII. The conclusions in the text are not materially affected by these errors, except that the claim of August to the highest average monthly growth in 1881, mentioned on page 57, becomes very doubtful.

V.—*A Contribution to the Chemistry of Nitroglycerine.* By MATTHEW HAY, M.D., Assistant to the Professor of Materia Medica in the University of Edinburgh.

(Communicated by Professor CRUM BROWN.)

Introductory.—In the course of an inquiry into the physiological and therapeutical action of alkaline nitrites, and allied substances, I was struck with the strong resemblance which the action of nitroglycerine bears to that of the nitrites.* The resemblance is, indeed, so well marked, that the action of the one may be held to be identical with that of the other, unless in respect of intensity. The suggestion, therefore, naturally occurred to me, that nitroglycerine is not a nitrate of glyceryl, as it is always represented, but a nitrite. For no ordinary nitrate, as an alkaline nitrate or nitrate of ethyl, nor any compound of glyceryl with another acid, as sulphuric acid, produces an action on the body at all resembling that of nitroglycerine. On referring to the various investigations which had been made for the purpose of ascertaining the chemical constitution of nitroglycerine, I found that none of them was sufficiently extended and exact to place beyond doubt its precise nature. The danger in manipulating so explosive a body had evidently prevented the various chemists from making a thorough examination of its composition. I at first thought that nitroglycerine might be a nitrite of glyceryl, having its nitrous acid so intimately combined with the glyceryl, that the acid did not exhibit its reactions when tested for in the usual way; just as the acids of other ethereal compounds will not yield their usual reactions, unless special means are taken to forcibly dissociate the acid from the base; for example, the acid of acetate of ethyl, or of chloride of ethyl. Certainly nitroglycerine gives no blue colour with a solution of starch and iodide of potassium and sulphuric acid, a very delicate test for the presence of nitrous acid. In order, however, to apply the test to the separated acid of nitroglycerine, I mixed an alcoholic solution of nitroglycerine with an alcoholic solution of pure caustic potash. The potash was ascertained to be free from nitrite, which I have frequently found present in small quantity in various specimens of ordinary potash. Decomposition of the nitroglycerine quickly occurred, and the fluid, when now tested for nitrous acid, was found to contain the acid in abundance, and so much of it, that for the moment I believed that nitroglycerine was, in reality, a nitrite of

* MATTHEW HAY, *Practitioner*, March and June 1883.

glyceryl; and hence the nature of its physiological action. Some estimations, however, of the quantity of the nitrous acid proved to me that whilst the larger portion of the nitrogen of the nitroglycerine appeared as nitrous acid in the decomposed products, yet a considerable portion was present in some other form.

The production of a large amount of an alkaline nitrite, when nitroglycerine is decomposed by an alkali, is a fact which, very strangely, has hitherto escaped the observation of chemists. MÜLLER and DE LA RUE * have, indeed, remarked the formation of nitrous acid in the spontaneous decomposition of badly-washed nitroglycerine; and HESS and SCHWAB † have even stated that nitrite of potassium is formed in addition to nitrate of potassium when potash is allowed to act on nitroglycerine, but they appear to have believed that the nitrite was formed in small quantity, and was quite a subsidiary product of the decomposition. Ever since RAILTON,‡ in 1855, published his paper on "Nitroglycerine and its Products of Decomposition by Caustic Potash," the decomposition has been invariably represented, and even in the most recent works on chemistry, by the equation:—$C_3H_5 .3(O.NO_2)+3HKOH=C_3H_5 .3OH+3(KO.NO_2)$; that is, caustic potash decomposes nitroglycerine with the formation of glycerine and nitrate of potash; and it is mainly from the supposed correctness of this equation that the formula for the constitution of nitroglycerine has been derived. WILLIAMSON,§ in the following year, gives an account of an investigation of nitroglycerine, and with results so exactly similar, even in detail, to those of RAILTON, that it is apparent that these chemists had made the investigation conjointly, although they published their results separately. RAILTON supplies a more minute account of his method of analysis of the products of decomposition, and it is not difficult to understand, from a careful perusal of it, how he was led to suppose that the nitrate of potash, which he obtained by crystallisation, was the only salt present. He applied no tests for nitrous acid, and he made no quantitative estimation either of the nitrate of potash or of the glycerine; and I may anticipate some of the results of the present investigation, and say that it is highly improbable that he obtained any glycerine at all, as he probably mistook for glycerine a syrupy residue consisting of other substances. No succeeding investigator of the chemistry of nitroglycerine has examined much more minutely the decomposition products; and the equation, therefore, remains as yet unaltered. It is evident that the constitution of nitroglycerine and the action of alkalies on nitroglycerine afford room for further investigation.

* MÜLLER und DE LA RUE, *Liebig's Annalen. d. Chemie.*, CIX. 122.

† HESS und SCHWAB, *Berichte d. deutsch. chem. Gesellschft.* Bd. XI. (1878), S. 192.

‡ RAILTON, *Qu. Journ. of Chem. Soc.*, vol. vii. p. 222.

§ WILLIAMSON, *Proc. Roy. Soc. Lond.*, vol. vii. p. 130.

Action of Fixed Alkalies on Nitroglycerine.—The nitroglycerine used was made by myself and not extracted from dynamite, as has been very frequently the case with previous investigators. I shall afterwards describe the mode of preparation employed. It is sufficient in the meantime to state, that whatever was the variation practised in the method of the production of the nitroglycerine, the products were perfectly uniform in character. The action of the alkali was examined both in aqueous and in alcoholic solutions. Nitroglycerine is so insoluble in water that it was decidedly preferable to make use of an alcoholic solution of the ether and mix it with an alcoholic solution of pure caustic potash (crystallised from its solution in alcohol). Absolute ethylic alcohol was employed in every instance.

When a moderately strong solution of caustic potash (1 in 10) is added to a solution of nitroglycerine of similar strength, the following phenomena are observed. The first few drops of the alkaline solution produce an orange-coloured precipitate, which, on the addition of more of the potash, assumes along with the whole fluid a deep reddish-brown colour. A large amount of heat is developed during the mixture, amounting almost to ebullition of the alcohol; a strong aldehyde-like odour is evolved, without any perceptible odour of ammonia or acrolein. The fluid quickly separates into two layers—the lower, and much the smaller, being partly of the nature of a solid precipitate, yet in great part syrupy and of a very deep reddish-brown colour, and containing nearly all the colouring matter formed by the decomposition of the nitroglycerine. The upper layer constitutes the bulk of the fluid, and is yellowish in colour, and at first muddy, but, after a few minutes, becomes quite transparent. The application of external heat is, as I have ascertained, quite unnecessary to complete the decomposition, although in most of my experiments I have with this object boiled the fluid over the water-bath for several minutes, sometimes to the entire dissipation of the alcohol, water being added as the alcohol is evaporated. When water is so added, the syrupy precipitate, in proportion to the amount of alcohol still present, becomes partially or completely dissolved, yielding a deep reddish-brown solution. If sufficient water is added to the fluid without previous removal of the alcohol, it is still possible to obtain a perfect solution of all the substances present. It was in such diluted solutions, obtained either in the one way or the other, that I estimated the amount of nitrite of potassium formed. This was effected by means of starch, potassium iodide, and dilute sulphuric acid, a thoroughly well-boiled 5 per cent. solution of starch, and containing 2 per cent. of potassium iodide, being employed. The blue colour obtained on the addition of these reagents was compared, as regards its intensity, with the colour produced by a similar amount of the reagents added to standard solutions of nitrite of sodium placed in test-tubes of the same diameter and used in the

same quantity as in the case of the nitroglycerine solution. The purity of the nitrite of sodium was previously ascertained by titration with a standard solution of permanganate of potash; and the strengths employed of the standard solutions of the nitrite were 1 in 500,000, and 1 in 1,000,000. The solution of decomposed nitroglycerine was diluted with distilled water until, on the addition of the starch reagent, a depth of blue was obtained precisely similar to that given by the strongest of the standard solutions of the nitrite. The solution was then diluted with an equal bulk of water, and, for the purpose of control, compared with the weaker standard solution. From the amount of dilution needed it was easy to estimate the quantity of nitrous acid present in the solution of the decomposed nitroglycerine. This method is only approximately correct, but it is the only method available. Any error was as far as possible eliminated by making the dilutions and comparisons with extreme care, and by occasionally repeating the estimation of the nitrous acid. The following were the results obtained. (The letters following the various specimens of nitroglycerine are for the purpose of identifying each specimen with its mode of preparation, which will be afterwards stated.)

I. Nitroglycerine, A.—1·1533 grms. dissolved in about 5 c.c. of alcohol, and treated with fully 1·5 grms. of caustic potash dissolved in about 12 c.c. of alcohol. Boiled over water-bath for half an hour, water being added to replace the evaporated alcohol, and heating continued until the whole of the alcohol was driven off. Fluid diluted to 30 c.c. 1 c.c. of this was further diluted, and employed for the estimation of the nitrous acid. A dilution corresponding to 1 of the original nitroglycerine in 620,000 of water was found to contain the same proportion of nitrous acid as the 1 in 1,000,000 standard solution of nitrite of sodium. The nitroglycerine had, therefore, produced a quantity of nitrous anhydride $\frac{(N_2O_3)}{2}$ corresponding to 62 per cent. of the anhydride in Na.O.NO, or 34·143 per cent. of the weight of the nitroglycerine.

A second estimation of the nitrous acid in the same solution of decomposed nitroglycerine gave 35·244 per cent. of N_2O_3.

II. Nitroglycerine, A.—1 c.c. of a 10 per cent. solution heated to the boiling point with a small excess of alcoholic solution of potash; diluted with two volumes of water and again heated to the boiling point, and the nitrous acid then estimated.

The nitroglycerine yielded 35·24 per cent. of $\frac{N_2O_3}{2}$.

III. Nitroglycerine, A.—Same in all respects as II.

The yield of nitrous anhydride was 35·24 per cent.

IV. Nitroglycerine, A.—Same as II., except that caustic soda was used instead of caustic potash. The decomposition presented the same appearances as when potash was used.

The yield of nitrous anhydride was 35·24 per cent.

V. Nitroglycerine, A.—Same as II., but no heat applied, and fluid freely diluted with water two minutes after the addition of the potash.

The yield of nitrous anhydride was 33·04 per cent.

VI. Nitroglycerine, B.—1 grm. dissolved in about 6 c.c. of alcohol, and heated with 12 c.c. of 12½ per cent. alcoholic solution of caustic potash. Boiled over water-bath to dissipate the alcohol, water being added to replace the alcohol.

The yield of nitrous anhydride was 34·96 per cent.

VII. Nitroglycerine, D.—1 grm. dissolved in 15 c.c. of alcohol, and heated with excess of potash solution.

The yield of nitrous anhydride was 34·41 per cent. Another estimation gave 34·96 per cent.

VIII. Nitroglycerine, F.—Same proportions of nitroglycerine and alkali as in VII.

The yield of nitrous anhydride was 34·96 per cent.

IX. Nitroglycerine, G.—Same proportions as VII.

The yield of nitrous anhydride was 35·24 per cent.

X. Nitroglycerine, G.—Same proportions as IX.

The yield of nitrous anhydride was 34·96 per cent.

XI. Nitroglycerine, N.—Same proportions as X.

The yield of nitrous anhydride was 35·24 per cent.

XII. Nitroglycerine (from NOBEL's dynamite).—Same proportions as X.

The yield of nitrous anhydride was 35·24 per cent.

SUMMARY OF ESTIMATIONS OF NITROUS ACID IN THE ALKALINE DECOMPOSITION-PRODUCTS OF NITROGLYCERINE.

No. of Analysis.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
Specimen of Nitroglycerine.	A	A	A	A	A	B	D	F	G	G	N	Dynamite.
Percentage of Nitrous Anhydride.	341·43	35·24	35·24	35·24	33·04	34·96	34·41	34·96	35·24	34·96	35·24	35·24

These analyses are amply sufficient to show that the amount of nitrous acid formed during the alkaline decomposition of nitroglycerine is neither small nor variable; and, assuming that nitroglycerine is a trinitrate of glyceryl, it corresponds remarkably with the supposition that two out of the three parts of nitric anhydride, which nitroglycerine contains, are reduced to nitrous anhydride; for the trinitrate of glyceryl ought theoretically to yield, if so reduced, 33·48 per cent., an amount which agrees very closely with that actually obtained, if due allowance be made for experimental error in a method which, although the best available, cannot claim to be exact.

It is open to suggestion, reasoning alone from these estimations of nitrous acid, that nitroglycerine is perhaps a di-nitrite of glyceryl, or a mono-nitrate di-nitrite of glyceryl. As opposed to its being one or other of those bodies, the fact that specimens of nitroglycerine, as B and D, prepared in presence of urea, were found to yield the same proportion of nitrous acid as the others, is of importance. Another weighty objection to its being a nitrite is that on passing nitrous anhydride gas into glycerine no substance at all resembling nitroglycerine was obtainable; although there was formed an oily liquid containing nitrous acid in combination, which, however, quickly decomposed in contact with water. This body has recently been investigated by Mr MASSON,* and he believes it to be the tri-nitrite of glyceryl. It is not probable that the di-nitrite will possess greatly different properties. Were nitroglycerine the di-nitrite, it ought to yield a much higher proportion of nitrous acid than was actually obtained. For these and various other reasons, it is not the di-nitrite, and much less the tri-nitrite. As to the possibility of its being a mono-nitrate di-nitrite, the objection as to the yield of nitrous acid is not by any means strong. For such a body ought theoretically to yield 30·89 per cent. of $\frac{N_2O_3}{2}$ (nitrous anhydride), an amount tolerably close to what was actually obtained. And amongst the alkaline decomposition products of nitroglycerine, it is not difficult to separate nitrate of potassium by crystallisation. But, on the other hand, the mono-nitrate di-nitrite ought to yield 21·5 per cent. of nitrogen, whereas, by actual experiment, Mr MASSON and myself have found that nitroglycerine contains a much lower percentage of nitrogen.

From these and other considerations, which will be referred to later on, it is impossible to avoid concluding that nitroglycerine is a tri-nitrate of glyceryl, and that two-thirds of its nitric acid is reduced to nitrous acid during the decomposition of the ether.†

I shall now give a brief account of the other substances, besides nitrite of potassium, which are formed when an alcoholic solution of potash acts on an alcoholic solution of nitroglycerine.

* Masson, *Journ. Chem. Soc.*, August 1883.

† *Vide* accompanying communication on "The Elementary Composition of Nitroglycerine."

Nitrate of potassium is, as I have mentioned, present in considerable quantity, and with the nitrite constitutes the larger portion of the reddish-brown, partly viscid, partly crystalline precipitate, which is formed in the decomposing fluid. I have not estimated the nitrate quantitatively; but there is every reason to believe, from the estimation of the total nitrogen by SCHLOESING'S method and from other circumstances, that the amount of the nitric acid corresponds very closely to one-third of the nitrogen present in nitroglycerine.

But nitrite and nitrate of potassium are not the only substances formed. I have also proved the presence of acetate of potassium, oxalate of potassium, and, doubtfully, of formate of potassium, neither of the two latter appearing to be present in large quantity. There is also a small amount of ammonia, and of a reddish-brown, resinous body, which imparts the dark colour to the decomposing fluid. There is likewise present a very curious and very interesting substance, which possesses the unusual power of forming a firm jelly with a very large proportion of absolute alcohol. In contradiction to RAILTON and WILLIAMSON, and previous investigators, I have found no glycerine, or only the merest trace of it. This is a new and most important fact.

In order to ascertain the presence and nature of these various decomposition-products, 6·67 grammes of pure nitroglycerine were decomposed with excess of potash in the usual manner, the mixture being allowed to boil for five minutes, and afterwards set aside for one day, to permit of the deposition of certain of the substances dissolved in the hot absolute alcohol. The supernatant fluid, which was transparent and of an orange colour, was then decanted, and the residue was again boiled with a fresh quantity of absolute alcohol, and again set aside for a day, when the alcohol was decanted and added to the previously decanted alcohol. This process was repeated a third time. The mixed alcoholic fluids ought to have contained the excess of caustic potash and the whole of the glycerine, were any present; and in the deep reddish-brown residue I expected to find nearly all the colouring matter, and all the salts insoluble in absolute alcohol, as the nitrite and nitrate of potassium.

The mixed alcoholic fluids were neutralised with alcoholic sulphuric acid in order to precipitate the potash as sulphate of potash. A voluminous white precipitate formed, which, after standing for some hours, was separated by filtration. The filtrate, although faintly acid, yielded another tolerably copious precipitate of sulphate of potash on the further addition of sulphuric acid, which was now added in distinct excess. Salts of potash were evidently present, dissolved in the alcohol; certainly, amongst others, the nitrite and acetate, as proved by testing. The precipitate was again removed by filtration, and the alcoholic fluid was now distilled fractionally in order to remove the more volatile substances, as the alcohol and acetic, formic and nitrous acids, the less volatile glycerine, if present, remaining in the retort. Distillation was continued until

four-fifths of the fluid had been evaporated. An equal bulk of water was now added to the residue, and distillation was continued until the alcohol was almost completely expelled. The residue was now saturated with pure barium hydrate, in order to remove the sulphuric acid, and then filtered; and the excess of barium was precipitated by a stream of carbonic acid gas, and the fluid was again filtered. The filtrate was now evaporated over the water-bath, and was quickly reduced to five or six drops of a golden yellow viscid residue. Treated with absolute alcohol, in which glycerine is freely soluble, it at once hardened, and was almost entirely insoluble in alcohol. It evidently consisted in part of a barium salt, as ascertained by testing. The alcoholic solution or extract was filtered, and, on evaporation, yielded about one drop of a yellowish syrup, much more viscid than glycerine, and pungent rather than sweet to the taste. A few minutes' further drying dessicated it to a hard scale. The syrup gave merely the faintest odour of acrolein when heated with acid sulphate of potash. I therefore concluded that this residue, which ought to have contained the greater part of the glycerine, were any present, contained practically none of that substance. The absence of glycerine from the alkaline decomposition products of nitroglycerine was confirmed by a second experiment, made with a still larger quantity of nitroglycerine, and in which no distillation was practised, and less opportunity therefore afforded for the decomposition or evaporation of the glycerine.

The deep reddish-brown residue, laid aside at the commencement, after being well washed and extracted with boiling absolute alcohol, was next examined. Dried at 100° C. for 24 hours, it weighed 14·65 grms., and was probably not even then absolutely dry, although very nearly so. The large amount of the residue is remarkable, as it weighs considerably more than the sum of the weights of the nitroglycerine decomposed, and of the potash necessary, according to RAILTON'S equation, for the decomposition of the nitroglycerine. This point will shortly receive an explanation.

The dried residue was perfectly soluble in water, forming even with a large volume of water a deep reddish-brown solution. A portion of the residue was dissolved in boiling water, and, after standing for some hours, large needle-shaped crystals of nitrate of potassium separated, which by re-solution and re-crystallisation were obtained in a perfectly pure form, and distinctly recognised to be nitrate of potassium. From another measured portion of the residue it was attempted to remove the nitrite of potassium and formate of potassium (if present), by treatment with strong acetic acid, and extraction with boiling absolute alcohol, in order to remove the acetate of potash and free acids thus formed, and to obtain in a tolerably pure state the nitrate of potassium for the purpose of a quantitative determination; but the method did not succeed.

One-half of the original dried residue was next dissolved in water, and

treated with moderate excess of dilute sulphuric acid, and heated for a few minutes. Red fumes were evolved with brisk effervescence; and a dark reddish-brown precipitate was formed, which evidently constituted the colouring matter of the decomposition products of nitroglycerine, although the colour was not wholly removed by the addition of the acid. The precipitate was collected on a filter, and washed with dilute acid and dried; it weighed 0·040 gram. It was insoluble in acid solutions, but freely soluble in dilute solutions of alkalies or alkaline carbonates, and was of a resinoid character, and is probably similar in nature to aldehyde-resin, or even to caramel.

As regards the peculiar alcohol-gelatinising body which I have mentioned as existing amongst the products of the alkaline decomposition of nitroglycerine, it was met with in the course of an examination of the decomposed products of 15 grms. of nitroglycerine, obtained in the usual way. The supernatant alcoholic fluid was treated with excess of dilute alcoholic sulphuric acid, in order to precipitate all the potash, both free and combined. The filtrate was afterwards neutralised, and the sulphuric acid precipitated by means of pure carbonate of barium. The evaporated filtrate yielded a residue which crystallised on cooling, and contained no glycerine, and which was very freely soluble in water without gelatinisation. It was also freely soluble in hot absolute alcohol; but on allowing the solution to cool, even if the proportion of the residue to the alcohol was 1 to 20 or 30, the solution became a firm, partly crystalline-looking jelly, which could not be poured out of the test-tube in which it formed. This body, whatever be its exact constitution, is certainly a very exceptional organic substance, and deserves further examination.

No gases are generated when potash acts on nitroglycerine in alcoholic solution. This was ascertained by placing the solution of nitroglycerine in a retort connected with a tube inverted over mercury, and boiling to drive out all the air. Alcoholic potash was then added, precautions being taken to prevent the simultaneous admission of air, and the boiling was continued for some time without any gas being formed.

These are the products formed when alcohol is the medium through which the potash attacks the nitroglycerine. Similar products are obtained when water is employed, and the only apparent difference is that, on account of the very sparing solubility of nitroglycerine in water, the decomposition proceeds with great slowness, fully two hours' boiling over the water-bath being required to effect the decomposition of one gram. of nitroglycerine in a strong solution of pure potash. Less red colouring matter is formed than when alcohol is employed, and much more oxalic acid seems to be produced; but the amount of nitrous acid is the same.

From this detailed account of the decomposition of nitroglycerine by caustic potash, it will be seen that the usual equation is very far from representing

what actually occurs. It is almost regarded as a fixed law in the chemical decomposition of compound ethers by alkalies, that the alkali unites with the acid of the ether and liberates the alcohol. This does not appear to be the case with nitroglycerine. For no glycerine is formed, and the acid is in great part reduced. But there is no doubt that the reduction of the greater portion of the acid is to be associated with the disappearance of the glycerine, which is evidently oxidised by the oxygen lost by the acid. Therefore, instead of glycerine, we have oxidation products of it, as acetic acid, oxalic acid, formic acid, &c. When nitroglycerine is being decomposed by potash, nitric acid and glycerine or glyceryl occur in a nascent and very active condition, the one as a powerful oxidising substance, the other as a readily oxidisable substance. As a consequence they act on each other, and two out of the three molecules of the nitric acid part each with an atom of oxygen to the glycerine or glyceryl, and this amount of oxygen is sufficient to completely oxidise and break up the glycerine, mostly, if not entirely, into certain organic acids, which, of course, will combine with a portion of the excess of the alkali used for the decomposition. That is one view; but there is another view, according to which the caustic potash may be regarded as taking an active part in the decomposition of the nascent glyceryl. When pure glycerine is melted with potash, it is well-known that acetate and formate of potash are produced along with free hydrogen.* The action is represented by the equation,—

$$C_3H_5(OH)_3 + 2KOH = KO.CHO + KO.C_2H_3O + OH_2 + 2H_2.$$

The decomposition effected by potash under these conditions may occur even in dilute solution if the glycerine be in a nascent state, more particularly if there be present at the same instant a highly oxidising body like nascent nitric acid, which is promoting the same form of decomposition, and is ready to grasp the nascent hydrogen. The amount of hydrogen set free is precisely the quantity needed to reduce two-thirds of the nitric acid of the nitroglycerine, and the other decomposition products of the equation given correspond tolerably closely with those actually ascertained to be formed. But if such a decomposition occurs, it implies that five, not three, molecules of hydrate of potash are required to decompose one molecule of nitroglycerine. In accordance with these views the action of caustic potash on nitroglycerine may be represented thus:—

(1) $$C_3H_5\cdot 3(O\cdot NO_2) + 3KOH = C_3H_5\cdot(OH)_3 + 3(K\cdot O\cdot NO_2).$$

Nitroglycerine. Potash. Glycerine. Potassium Nitrate.

and

(2) $$C_3H_5\cdot(OH)_3 + 2KOH = KO\cdot CHO + KO\cdot C_2H_3O + OH_2 + 2H_2.$$

Glycerine. Potash. Potassium Formate. Potassium Acetate. Water. Hydrogen.

* Dumas et Stas, *Ann. Chim. Phys.*, lxxiii., 148.

(3) $3(KO.NO_2)+2H_2=KO.NO_2+(2KO.NO)+2OH_2$.

Potassium Nitrate. Hydrogen. Potassium Nitrate. Potassium Nitrite. Water.

or, combining these stages of the supposed reaction into one equation :—

(4) $C_3H_5.3(O.NO_2)+5KOH=KO.NO_2+2(KO.NO)+KO.CHO+KO.C_2H_3O+3OH_2$.

Nitroglycerine. Potash. Potassium Nitrate. Potassium Nitrite. Potassium Formate. Potassium Acetate. Water.

In equation (1) it might have been more in harmony with the view advanced that the glycerine should have been represented as glyceryl and water, to indicate more completely its nascent state.

There is every reason to believe that equation (4) is substantially and approximately correct, although in respect of the oxidation products of glycerine these may vary in their nature and proportions. Besides being in accordance with the results of the examination of the products of decomposition, it is supported, as regards the amount of potash required, by the following experiments :—

According to RAILTON's equation, one part of nitroglycerine requires for its complete decomposition 0·741 parts of potassium hydrate; according to the equation just given the proportion is as 1 : 1·235. If less of potash is used than in the latter proportion, then, if the latter equation be correct, complete decomposition will not occur, and a quantity of nitrous acid will be produced corresponding to the amount of potash employed; and the solution of the products of decomposition will remain neutral until more than the requisite proportion of potash (1·235 to 1) has been added. In the following four experiments nitroglycerine, F., was employed in every instance, and a certain quantity of it was dissolved in alcohol and decomposed by an alcoholic solution of a given weight of pure potash, freshly crystallised from alcohol, and as free as possible from carbonate; the mixture being boiled for ten minutes, diluted with water, and again boiled for ten minutes.

No. of Experiment.	Weight of Nitroglycerine.	Weight of Potassium Hydrate.	Yield of Nitrous Anhydride, expressed as percentage of Nitroglycerine used.		Reaction of Decomposed Fluid.
	Grms.	Grms.	Calculated according to Author's equation.	Found:	
I.	1	0·80	21·68	23·23	Neutral.
II.	1	1·00	27·11	28·68	Neutral.
III.	1	1·24	33·48	34·69	Very slightly alkaline.
IV.	1	1·50	33·48	34·69	Alkaline.

The degree of alkalinity of (IV.) was ascertained by titration with a standard solution of sulphuric acid (30 in 1000). 6·2 c.c. of standard acid were required for complete neutralisation, which is equivalent to 0·203 grms. of potassium hydrate, which, subtracted from 1·50 grms., the quantity of potash originally added, gives 1·297 grms. as the amount of potash actually used up, or a little more than the theoretical quantity. It is noteworthy in these experiments that where less than five molecules of potash, although more than three, were added to one of nitroglycerine, a quantity of nitroglycerine could be observed to remain undecomposed, as it was precipitated on the addition of water to the alcoholic mixture, proving that when potash acts on nitroglycerine in presence of excess of the latter, according to the equation I have adopted, the potash is used up in thoroughly decomposing each molecule of the nitroglycerine, and does not partially decompose a greater number of molecules. The respective yields of nitrous acid are alone sufficient to prove this.

The amount of potash required for the decomposition of nitroglycerine is interesting in connection with a method described by BECKERHINN * a few years ago for the estimation of the degree of acidification of the ether, whether tri-, di-, or mono-nitrate, in which, after adding what he considered to be excess of caustic potash, he titrated the excess with normal oxalic acid. But his calculations were based on the accuracy of RAILTON'S equation. It is very difficult, therefore, to understand how he could possibly have obtained satisfactory results, although he claimed to have done so, and quoted two analyses. In the following year HESS and SCHWAB † denied the correctness of his method, and made analyses according to it, but obtained widely different results, yet still acknowledging RAILTON'S formula, and ascribing the faultiness of the method to various minor circumstances.

Action of Ammonia.—The volatile alkali seems to act on nitroglycerine in the same manner as the fixed alkalies, but not so energetically. When excess of strong ammonia was added to an alcoholic solution of nitroglycerine, there was no immediate decomposition of the nitroglycerine, as is the case when potash or soda is added. The resultant mixture remained colourless and showed no precipitate. It was then placed over the water-bath and heated all but to ebullition for one hour; and in order to preserve excess of ammonia, more of the reagent was added from time to time. It now gradually assumed a deep reddish-brown colour, almost deeper than that observed in decomposition with potash. The maximum intensity of colour was reached after half an hour's heating, so that ammonia acts much more slowly than potash. The amount of nitrous anhydride obtained was equivalent to 34·5 per cent. of the nitroglycerine

* BECKERHINN, *Sitzungsb. d. Wien. Akad.*, Bd. lxxiii. (1876), Abth. 2, S. 235.

† HESS u. SCHWAB, *Ibid.*, Bd. lxxv. (1877), Abth. 1, S. 702.

used, or a proportion exactly similar to that produced by the action of a fixed alkali.*

Action of Alkaline Carbonates.—Nitroglycerine was dissolved in slightly diluted alcohol in order to permit the solution in it of carbonate of potash, which was afterwards added in the form of a concentrated aqueous solution. The mixture slowly assumed a reddish colour even in the cold. Heated over the water-bath, the nitroglycerine tolerably rapidly underwent decomposition, and the fluid became of a fairly deep reddish-brown colour. The fluid was heated for one hour, and water was added as the alcohol became evaporated. The yield of nitrous anhydride was 35·24 per cent., or the same as when caustic potash is used. In a second experiment the yield was exactly the same. Using a five per cent. alcoholic solution of nitroglycerine, and boiling it with excess of carbonate of potash, it was ascertained that complete decomposition occurs in about ten minutes.

Action of Phosphate of Soda (Na_2HPO_4).—This salt is acid in constitution, but alkaline in reaction. Added in concentrated aqueous solution to a one per cent. alcoholic solution of nitroglycerine, and heated over the water-bath, the phosphate commenced to decompose the nitroglycerine three to four minutes after the mixture was fully heated, as was evidenced by the appearance of a yellowish tint gradually deepening to an orange-red. After heating for an hour and a half, slightly diluted alcohol being added occasionally, a yield of 13·76 per cent. of nitrous anhydride was obtained. In another experiment, after heating a similar mixture for forty minutes, 13·21 per cent. of nitrous anhydride was obtained. On both occasions the nitrous acid was estimated in one half of the fluid, and it was observed, in diluting the fluid with water, that a considerable amount of nitroglycerine was precipitated. In the second experiment, by adding potash to the remaining half of the fluid, and heating for a few minutes, and then estimating the nitrous acid, 34·41 per cent. of nitrous anhydride was obtained, proving that no nitrous acid had been set free by the phosphate of soda, which, in the absence of sufficient alkali,

* It is somewhat remarkable that the yield of nitrous acid was as great as when a fixed alkali was used; since it is well known that a solution of nitrite of ammonia readily undergoes decomposition when heated; and it was to be expected that the estimated yield of nitrous acid would have been diminished by the occurrence of such a decomposition in the heated fluid. In order to make certain that the result obtained was correct, and that under the conditions of the experiment such a decomposition did not occur, or occurred only to a limited extent, I have, since the paper was read, repeated the experiment. This I have done on two occasions, and with separate quantities of pure nitroglycerine. On the first occasion only 29·6 per cent. of nitrous anhydride was obtained, but, on the second, 34.1 per cent., or very nearly what was obtained in the experiment recorded in the text. The nitrite of ammonia formed by the splitting up of the nitroglycerine would appear, therefore, to undergo very little decomposition under the conditions in which it is placed. This may be due to the excess of free ammonia always maintained in the decomposing mixture, or to the low degree of heat applied, as, in order to prevent the rapid escape of gaseous ammonia, heat was applied short of ebullition of the fluid, or, more properly, of the escape of ammonia in the form of bubbles of gas; or it may be that the highly concentrated alcohol in which the nitroglycerine was dissolved hindered the decomposition of the nitrite.

might have been decomposed into nitric acid and nitric oxide, or evaporated off. This form of control-analysis is the more necessary when the salt or substance employed to act on the nitroglycerine is neutral; and in such circumstances I have always made use of it.

Phosphate of soda appears, therefore, to act on nitroglycerine in much the same manner as alkalies and alkaline carbonates, only very much less powerfully.

Action of Chloride of Sodium.—Excess of a concentrated solution of the pure salt was mixed with a one per cent. alcoholic solution of nitroglycerine. The salt was not precipitated, as the alcohol contained a little water. The mixture was heated for thirty-five minutes. There was no perceptible change of colour, and the quantity of nitrous acid did not amount to more than a fraction of a per cent. of the nitroglycerine used. The starch reagent yielded no blue colour with the fluid until sulphuric acid was added. The trace of nitrous acid was therefore present as a nitrite. One half of the fluid was treated with potash, and from it was procured an amount of nitrous anhydride corresponding to 35·25 per cent. of the nitroglycerine. The chloride of sodium had not, therefore, decomposed the nitroglycerine and lost the nitrous acid by decomposition or evaporation.

Chloride of sodium possesses, therefore, extremely little action on nitroglycerine.

Action of Hydrochloric Acid.—1·6 c.c. of the strong acid were diluted with 2 c.c. of water and added to 10 c.c. of a one per cent. alcoholic solution of nitroglycerine; and the mixture was heated over the water-bath for half an hour. It was then found to contain a trace of nitrous acid, not exceeding a small fraction of a per cent. of the nitroglycerine. One half of the fluid, heated with excess of caustic potash, and thus completely decomposed, yielded nitrous anhydride corresponding to 13·5 per cent. of the nitroglycerine. This showed that the hydrochloric acid had decomposed about 39 per cent. of the nitroglycerine, but whether with the formation of nitrous acid, it is quite impossible to say. For even had nitrous acid been formed, it would have been driven off by the boiling, or decomposed in contact with the water of the fluid.

Hydrochloric acid, therefore, in large excess, decomposes nitroglycerine much more slowly than a caustic alkali or even an alkaline carbonate, and not much more quickly than phosphate of soda.

Action of Sulphuric Acid.—0·5 c.c. of strong sulphuric acid was diluted with 1 c.c. of water, and mixed with 10 c.c. of a one per cent. solution of nitroglycerine, and heated for half an hour. At the end of this period the fluid did not contain more than the merest trace of nitrous acid. One half of the fluid, boiled with potash, yielded nitrous anhydride corresponding to 29·7 per cent. of the nitroglycerine. The sulphuric acid had, accordingly, decomposed 11·3 per cent. of the nitroglycerine employed.

Sulphuric acid, in the proportion used, would appear, therefore, to act less energetically than hydrochloric acid on nitroglycerine. Concentrated sulphuric acid in the cold seems to have almost no action, as is proved by the method of the preparation of nitroglycerine.

Action of Sulphuretted Hydrogen.—According to De Vrij,* an ethereal solution of nitroglycerine is readily decomposed by sulphuretted hydrogen with a copious precipitation of sulphur.

In order to test the truth of this observation, I submitted two ten per cent. solutions of nitroglycerine—the one in absolute alcohol, the other in ether—to the action of a stream of sulphuretted hydrogen gas. But although the gas was allowed to pass in a rapid stream through each solution for fifteen minutes, yet not the slightest trace of decomposition occurred, as was evidenced by no change of colour, and the absence of nitrous acid and precipitated sulphur and other decomposition products; even although, in the case of the alcoholic solution, its temperature was raised to near the boiling point and the gas passed for fifteen minutes longer. Nitroglycerine was precipitated abundantly from both solutions on the addition of water. These experiments were more than once made, and always with the same result.

It must, therefore, be concluded that sulphuretted hydrogen has no action, or at most a very slow action, on pure nitroglycerine. The opposite experience of De Vrij was probably due to his having used an impure nitroglycerine.

Action of Alkaline Sulphides.—These act very energetically on nitroglycerine, and decompose it, if in alcoholic solution, as rapidly as alkalies alone do. On adding a solution of ordinary sulphide of potassium, or sulphide of ammonium, to an alcoholic solution of nitroglycerine, the mixture quickly assumes a deep reddish-brown colour, and its temperature rises; and the action of the sulphide is completed with a sudden and most abundant precipitation of sulphur in every part of the mixture simultaneously. No gas is given off; and, contrary to expectation, after being boiled with excess of the sulphide for half an hour, filtered to remove the sulphur, and treated with acetate of lead and again filtered to remove the sulphuretted hydrogen of the sulphide, it yielded evidence of the presence of nitrous acid to the extent of a little less than half the proportion yielded by a purely alkaline decomposition. It would appear, therefore, that the whole of the nitrous acid set free in the decomposition of the nitroglycerine by the alkali of the sulphide is not acted on by the sulphuretted hydrogen of the sulphide. For we may assume, since sulphuretted hydrogen does not of itself attack nitroglycerine, that it is the alkali of the sulphide which takes the initial step in the decomposition of the nitroglycerine; the sulphuretted hydrogen playing a subsidiary part, and merely acting on the nascent products of the decomposition effected by the alkali.

* De Vrij, *Journ. Pharm.* [3], xxviii., 3; and Gmelin's *Handbook of Chemistry*, x. p. 562.

But why the whole of the nascent nitrous acid should not thus be decomposed by the sulphuretted hydrogen I do not, in the meantime, attempt to explain, beyond suggesting that the nascent nitrous acid may in part combine with the alkali; and, once so united, it is incapable of being acted on by the sulphuretted hydrogen.

But the sulphuretted hydrogen does not play an altogether passive part in the actual decomposition of the nitroglycerine itself, for when an aqueous solution of an alkaline sulphide, such as potassium sulphide or ammonium sulphide, is poured over pure undissolved nitroglycerine, and the mixture vigorously shaken, the solution gradually becomes reddish, and the temperature rises, and apparently, when the temperature has risen sufficiently, the whole or nearly the whole of the nitroglycerine suddenly decomposes with a copious formation of sulphur. In fact, the nitroglycerine seems to become suddenly converted into a mass of sulphur. It will be remembered that when potash alone is allowed to act on nitroglycerine under similar circumstances, the decomposition proceeds very slowly. The presence, therefore, of sulphuretted hydrogen very greatly promotes the decomposition of nitroglycerine; but in what particular manner I have not endeavoured to ascertain.

Action of Water.—In order to ascertain to what extent water when boiled with nitroglycerine is capable of decomposing it, a given quantity of a saturated aqueous, and, owing to the insolubility of nitroglycerine in water, a necessarily weak, solution of nitroglycerine was heated over the water-bath. After ten minutes' active heating, the fluid exhibited no signs of decomposition, and contained no trace of nitrous acid. It was then continuously heated for three hours. It still remained colourless, and on the addition of starch and iodide of potassium gave no blue; but when these reagents were added along with dilute sulphuric acid, a distinct blue was obtained. The nitrous acid present was evidently combined with some other decomposition product of the nitroglycerine; it was estimated and found to amount to 1·7 per cent. of the whole nitroglycerine employed. A given portion of the fluid was heated with potash, in order to learn how much of the nitroglycerine remained undecomposed, and a quantity of nitrous acid (nitrous anhydride) was obtained, equivalent to 8·88 per cent. of the whole nitroglycerine; from which it is to be concluded that 73·48 per cent. of the nitroglycerine had been decomposed by heating with water for three hours. It is to be considered that a portion of this may have been lost by simple evaporation, although this was to a certain extent avoided by heating in a long-necked Florence flask.

Action of Alcohol.—A one per cent. solution of nitroglycerine in absolute alcohol was heated over the water-bath for one hour, the alcohol being renewed from time to time. There was no change in colour, and nitrous acid could not be detected, even when sulphuric acid was added along with the usual reagents. A portion of the fluid was decomposed with potash, and the nitrous anhydride

obtained was found to be equivalent to 33·45 per cent. of the whole nitroglycerine, proving that the nitroglycerine had not been apparently decomposed by heating with alcohol.

From this it is evident that the alcohol used as a menstruum in ascertaining the action of other substances on nitroglycerine did not of itself aid in the decomposition of the nitroglycerine.

Preparation of Nitroglycerine.—After I had observed that nitroglycerine yielded, when decomposed with an alkali, a large amount of nitrous acid, and being fully sensible of the insufficiency of existing analyses to determine the elementary composition of nitroglycerine, doubts arose in my mind, as I have already stated, as to whether nitroglycerine was actually a tri-nitrate of glyceryl. I have already given some important reasons in connection with its alkaline decomposition products for regarding it as the tri-nitrate, and not as any form of a nitrite. But I have thought it advisable to supply what additional proof could be obtained of its composition from a consideration of the yield of nitroglycerine from a given weight of glycerine. For this purpose I prepared nitroglycerine with various proportions of glycerine and acids, in order to ascertain the highest possible yield of nitroglycerine. Another important object which I had at the same time in view was to learn how far such variations in the method of the preparation of nitroglycerine might affect its composition. The latter object was very desirable, owing to the very discrepant statements which have been made by previous investigators as to nitroglycerine consisting entirely of tri-nitrate of glyceryl, or of a mixture of the tri-nitrate with the di-nitrate and mono-nitrate.

In the preparation of the nitroglycerine, PRICE'S pure glycerine, dried for six hours in the air-bath at a temperature of 120°C, was always employed ; the specific gravity, after drying, was 1·260 at 14°C. The acids were each of two strengths—nitric acid, of a specific gravity of 1·422 (referred to as *strong* nitric in what follows), and 1·494 (referred to as *fuming* nitric acid) ; sulphuric acid, of a specific gravity of 1·844 (referred to as *strong* sulphuric acid), and 1·984 (referred to as *fuming* sulphuric acid) ; all at 15·5°C. In every instance the nitric and sulphuric acids were first mixed and placed in a vessel containing salt and ice, and cooled to below 0°C. In certain cases where urea was also used, it was added to the nitric acid previous to mixture with the sulphuric acid. Into the cooled mixture of the acids the glycerine was slowly dropped and well mixed by constant stirring, the temperature, as ascertained by a thermometer, never being permitted to rise above 10°C. After standing for a variable time, the mixture was poured into a large and measured quantity of cold water, when the nitroglycerine was precipitated. It was now very carefully collected, after thorough stirring with the water, and was in this slightly impure state dried in the air-bath at 70°C. It dried quickly, but assumed a yellowish tint, and had a pungent acid odour. The weight of the dried nitro-

glycerine, increased by the weight of the nitroglycerine known to be lost by solution in the water into which it had been thrown, and which was calculated from a solubility of 1 in 800, gave the total yield of nitroglycerine. The nitroglycerine before being used for any other purpose, as for analysis, was thoroughly shaken with successive quantities of distilled water until it was perfectly pure. The first precipitation and washing was, I am satisfied, quite sufficient to remove by far the largest part of the impurities, and the trace of these left did not interfere to any noteworthy extent with the actual weight of the nitroglycerine. In certain cases I checked the weight of the raw nitroglycerine by weighing the product after it had been thoroughly purified, and, again allowing for loss by washing, according to the quantity of water used, I obtained almost the same weights. A note of the time for which the mixture of the acids and glycerine was allowed to stand before being thrown into water was always kept.

Figure of Reference for the Various Products.	Weight of Glycerine. — Grms.	Weight of Nitric Acid.		Weight of Sulphuric Acid.		Time of Standing after complete Mixture.	Yield of Nitroglycerine.	
		Strong. — Grms.	Fuming. — Grms.	Strong. — Grms.	Fuming. — Grms.		Absolute. — Grms.	Percentage.
A.	12·4	...	30	75	...	10 mins.	...	...
B.	6·1	urea, 2 grms.	15	30	...	8 „	...	...
C.	10·4	30	urea, 1 grm.	30	...	5 „	1·7	16·3
D.	8·8	25	urea, 1·5grm.	50	...	5 „	9·486	107·8
E.	10·2	30	...	60	...	5 „	16·71	163·8
F.	10·8	30	...	90	...	5 „	18·79	175·6
G.	10·6	30	...	90	...	60 „	19·11	180·2
H.	9·4	...	20	20	20	30 „	19·06	202·7
I.	10·2	...	20	10	30	30 „	18·80	184·3
J.	9·6	30	...	30	...	30 „	2·89	30·1
K.	10·3	...	30	90	...	30 „	23·40	227·1
L.	10·5	...	30	30	30	30 „	24·50	233·3
M.	10·25	...	30	20	40	50 „	23·75	231·7
N.	10·0	...	30	60	...	30 „	23·40	234·0

The specific gravity of each nitroglycerine was taken, and was found to vary from 1·601 to 1·604, depending on the temperature. From this fact alone, of the close agreement in specific gravity exhibited by the various products, it might be fairly concluded that they were all one and the same body. Their uniformity has, however, been more certainly proved by their all having been ascertained to contain the same percentage of nitrogen.* Indeed, in whatever way tested, whether as regards specific gravity, yield of nitrogen and of nitrous acid, and behaviour towards solvents, they were all found to agree precisely. The great difference in the amounts of the various products cannot therefore be regarded as being due to a difference in the nitroglycerine. It seems to be almost entirely caused by the differences in the quality and proportion of the

* *Vide* HAY and MASSON's Paper on "The Elementary Composition of Nitroglycerine."

acids. The highest yield of nitroglycerine is that of N., where 234 parts of nitroglycerine were procured from 100 parts of glycerine. Now, glycerine, $C_3H_3.(OH)_3$, ought theoretically to produce 246 per cent. of tri-nitrate of glyceryl, $C_3H_5.3(O.NO_2)$. Making allowance for inevitable loss from various intelligible causes, it may, therefore, be fairly deduced that the experimental yield of nitroglycerine strongly favours nitroglycerine being regarded as the tri-nitrate. If it were the tri-nitrite, $C_3H_5.3(0.NO)$, the theoretical yield would be 194 per cent.; if the di-nitrite, $C_3H_5.HO.2(O.NO)$, 163 per cent.; and if the mono-nitrate di-nitrite, $C_3H_5.(O.NO_2).2(O.NO)$, 211 per cent. The actual yield very distinctly exceeds any of these.

With regard to the conclusions of practical and commercial importance which may be drawn from these various methods of preparing nitroglycerine, it is to be observed that there is a distinct advantage, as is generally recognised, in employing fuming nitric acid (compare (F) and (G) with (K)); that where fuming nitric acid is used, no benefit is to be obtained from the employment of fuming sulphuric acid (compare (L) and (M) with (K) and (N)); that two parts of ordinary sulphuric acid to one part of fuming nitric acid appears to give as good a yield as any other proportion of acids, and quite as large a yield as when more sulphuric acid is used (compare (N) with (K)); and that the yield is not to any considerable extent increased by allowing the acids and glycerine to remain in contact for some time after mixture, as some chemists have advised (compare (F) with (G), and (L) with (M)).

Characters of Nitroglycerine.—I have been somewhat surprised to find that a large number of contradictory statements exist as to the ordinary physical characters of nitroglycerine. Whilst a few authors describe it as colourless, by others it is referred to as a pale yellow oil, even in the most authoritative modern works on Chemistry, as FEHLING'S *Neues Handwörterbuch der Chemie** and BEILSTEIN'S *Handbuch der Organischen Chemie*.† Now nitroglycerine is perfectly colourless when pure. As obtained from dynamite, it is certainly yellow, but the colour is due to decomposition having taken place, which, I believe, is to little or no extent spontaneous in character, but rather proceeds from the presence of a little of the weak soda which is invariably employed in the manufacture of nitroglycerine for the purpose of removing the traces of the acids. The soda neutralises the acids, but it at the same time decomposes the nitroglycerine, and imparts the colour so commonly ascribed to it as an inherent property. Nitroglycerine washed with distilled water has in my possession never become in the slightest degree coloured, even although kept in an open capsule, freely exposed to the air, but away from dust, for two months; in stoppered bottles it has not during the last seven months showed the least sign of decomposition. Even in solution in water, or in alcohol, it keeps almost equally well. More than one author states that it decomposes and becomes red on

* Bd. iii. 1878. † S. 529, 1881.

being heated over the water-bath. I have heated pure nitroglycerine to the highest possible temperature over the water-bath for four hours, and have never observed the development of the slightest colour or decomposition. When it decomposes under such circumstances it probably contains free acid or alkali. Again, it is stated by RAILTON* that when placed in the bell-jar of the air-pump it rapidly undergoes decomposition. In the course of the investigation by Mr MASSON and myself, we have kept nitroglycerine for twelve days *in vacuo* without its exhibiting the slightest signs of decomposition. The decomposition of RAILTON's preparation must have been due to its impurity.

Nitroglycerine has no odour when cold, but emits a pungent odour when heated. Although odourless in the cold, it nevertheless seems to be undergoing slight volatilisation; for after working with it for a short time, and without directly touching it with the fingers, I have generally experienced its physiological effect in a slight degree. Its taste is sweet, and not unlike that of glycerine, but is more pungent.

As regards its solubility, 1 gram. dissolves in about 800 c.c. of water; with difficulty in 3 c.c. of absolute alcohol, easily in 4 c.c.; in 10·5 c.c. of rectified spirit (sp. gr. 0·846); in 1 c.c. of methylic alcohol (sp. gr. 0·814); in 4 c.c. of methylated spirit (sp. gr. 0·830); in 18 c.c. of amylic alcohol; in every proportion in ether; so also in chloroform, in glacial acetic acid, and in carbolic acid; in less than 1 c.c. of benzol; in 120 c.c. of carbon bisulphide; and to a very limited extent, if at all, in glycerine.

Method of Estimating Nitroglycerine. — In cases where nitroglycerine cannot be estimated gravimetrically after extraction with one of its solvents, a method based on the evident constancy of the amount of the nitrous acid produced in its decomposition with potash may be safely adopted. I have made use of this method for ascertaining the degree of its solubility in water, and for other quantitative estimations in the course of this investigation, and it is not difficult to apply. The materials necessary are a standard solution of pure nitrite of sodium (titrated with permanganate) of the strength of 1 in 1,000,000, a well-boiled solution of starch and iodide of potassium, dilute sulphuric acid, and pure potash, ascertained to be free from nitrous acid. Heat the fluid containing the nitroglycerine with excess of potash, and dilute with water until, in comparison with the standard solution of nitrite of sodium, it yields a blue colour with the starch mixture and sulphuric acid of precisely the same depth. From the degree of dilution required the amount of nitrous anhydride present can be readily calculated, and this amount multiplied by $\frac{100}{33{\cdot}48}$ (33·48 being the percentage of nitrous anhydride yielded by nitroglycerine) will give the quantity of nitroglycerine.

* *Op. cit.*

VI.—*The Elementary Composition of Nitroglycerine.* By MATTHEW HAY, M.D., and ORME MASSON, M.A., B.Sc.

(Communicated by Professor CRUM BROWN.)

Nitroglycerine is commonly described as the tri-nitric ether of glyceryl, and the formula $C_3H_5(O.NO_2)_3$ is accorded to it. This theory of its composition is based (1) upon its mode of formation; (2) upon the statement, made by RAILTON, WILLIAMSON, and others, that it is decomposed by potash into potassium nitrate and glycerine; (3) upon several estimations of the nitrogen which it contains, and one comparative estimation of its carbon. The second argument cannot be accepted, as it has been shown by one of us that the decomposition does not take place in the way stated;* and the analytical results which have been obtained by the various investigators are so incomplete and mostly so imperfect, and differ so greatly among themselves, that they cannot be taken as affording any proof of the composition of the substance. It seemed to us, therefore, desirable that some accurate estimations should be obtained, not only of the nitrogen but of the carbon and hydrogen. A brief *résume* of previous analytical results will show that this is the case.

RAILTON,† in 1855, attempted to estimate the relative quantities of carbon and nitrogen by LIEBIG'S method. The ratio of the volume of carbonic acid to that of nitrogen required by the formula is 2:1. RAILTON obtained results varying from 2·156:1 to 1·912:1; so that, although they are on the whole in favour of the formula, they cannot be regarded as satisfactory. He made no attempt to estimate the carbon and hydrogen absolutely, as he found it impossible to dry his nitroglycerine, even in an exhausted receiver, on account of its great tendency to decompose. This proves that the substance was impure, as we have found pure nitroglycerine to be perfectly stable in the air and *in vacuo*.

WILLIAMSON,‡ in the following year, gave an account of the composition of nitroglycerine, which agrees so exactly with RAILTON'S in every detail, that there can be no doubt that their experiments were made in conjunction, although published separately and without reference to each other.

HESS,§ in 1874, estimated the nitrogen in commercial nitroglycerine

* See the preceding paper: "Contribution to the Chemistry of Nitroglycerine," by MATTHEW HAY.

† RAILTON, *Quart. Jour. Chem. Soc.*, vol. vii. p. 222.

‡ WILLIAMSON, *Proc. Roy. Soc.*, vol. vii. p. 130.

§ HESS, *Zeitschr. f. anal. Chem.*, 1874, S. 257.

obtained from various sources. He used different methods and got results varying from 13·7 to 16·6 per cent., the percentage required by the formula of glyceryl tri-nitrate being 18·5. From this he concluded that commercial nitroglycerine contains the mono- and di-nitrate, as well as the tri-nitrate.

Beckerhinn,* in 1876, described an extremely elaborate method for the estimation of the carbon and hydrogen, but gave no results.

Hess and Schwab,† in 1877–78, made some nitrogen determinations by Dumas's method. In one sample they found 15·72 and 15·65 per cent., and in another (from Nobel's Zamky manufacture of 1872) they found 16·13, 16·12, and 16·12 per cent., though this was the same liquid which four years earlier had yielded Hess only 14·0 per cent.

Sauer and Ador,‡ in 1877, estimated by three methods the nitrogen in nitroglycerine obtained from dynamite. First they used Reichardt's modification of Schloesing's method, after decomposing the liquid with potash, and obtained from 12·3 to 14 per cent. Next they tried the ignition with soda-lime process, but found that only 2 to 3 per cent. of the nitrogen was evolved as ammonia. Finally they made four determinations by Dumas's method, using nitroglycerine obtained from three different samples of dynamite; and in this case they obtained from 18·35 to 18·52 per cent., which agrees very closely with the percentage calculated from the formula, but differs widely from that obtained by Hess and Schwab by the same method.

The nitroglycerine which we employed in our analyses was made by adding, drop by drop, one part by weight of Price's pure glycerine to a mixture of two parts of nitric acid (sp. gr. 1·49) and six parts of sulphuric acid (sp. gr. 1·84), the mixture being surrounded with ice and kept at a temperature never exceeding 10° C. Five minutes were allowed to elapse before pouring the mixture into water; and the precipitated nitroglycerine was then well washed eight times with large volumes of distilled water, and dried for seven hours in an air-bath at a temperature of from 70° to 80° C. Finally, it was allowed to stand twelve days over sulphuric acid in the exhausted receiver of an air-pump. Not the slightest sign of decomposition ensued; and it was found that the nitroglycerine, after standing one week *in vacuo*, had lost less than one-tenth per cent. of its weight, which shows that it was practically dry from the first. It was perfectly colourless and transparent. Its specific gravity at 14°·5 C. was 1·601.

The carbon and hydrogen were estimated by ignition in a tube closed and drawn out at one end and filled with copper oxide and metallic copper in the usual manner. At the termination of the ignition the drawn-out point was

* Beckerhinn, *Sitzgsber. Wien. Akad.*, Bd. lxxiii., Abth. ii. S. 240.

† Hess *u.* Schwab, *Ber. Deutsch. chem. Gesellschft.*, Bd. xi. S. 192.

‡ Sauer *u.* Ador, *Ibid.*, Bd. x. S. 1982.

broken, and a stream of oxygen was passed through to ensure the complete combustion of the carbon. In our first experiment the nitroglycerine was weighed out in a short glass tube, and this was dropped into the combustion tube; but an explosion occurred at an early stage of the ignition, which, although damaging the furnace and slightly injuring one of us who happened at the moment to be within a few inches of the tube, satisfied us that the explosive force of the quantity of material employed (0·23 grm.) was not so great as to prevent our continuing the experiments with the adoption of very ordinary precautions. It was next attempted to burn the nitroglycerine in the form of dynamite, using pure and previously ignited *Kieselguhr* as the absorbent; but this also gave rise to an explosion, though of greatly diminished violence. Ultimately it was found that the combustion could be performed without any risk of explosion by adopting the following method. A quantity of the liquid (from ·2 to ·4 grm.) was weighed out in a porcelain boat containing finely-divided copper oxide, and was then covered with another layer of the oxide. The boat was dropped into the combustion tube, and its contents were scraped out and well mixed up with the granulated copper oxide by means of a long bent copper wire. The tube was then filled up in the customary manner. The chief difficulty attending this method is to avoid the introduction of moisture by the copper oxide and consequent raising of the hydrogen percentage. The precautions taken against this were increased in each experiment, so that the last hydrogen determination is probably the most reliable, while the first is considerably too high. All the combustions were conducted with unusual slowness. The same means was employed for filling the tube in the nitrogen determinations by DUMAS's method.

	Calculated.	Found.				
		I.	II.	III.	IV.	V.
C_3, . . .	15·86	16·05	15·89	15·80	...	...
H_5, . . .	2·20	2·99	2·40	2·08	...	...
N_3, . . .	18·50	...	...	...	17·93	17·97
O_9, . . .	63·44	...	...	...	...	...

Two nitrogen determinations were also made with the same nitroglycerine before it had been placed *in vacuo*, and the results, though slightly higher, hardly warrant the belief that there was any difference in the composition. They were (1) 18·25 and (2) 18·06.

We consider that the above figures prove nitroglycerine to be glyceryl tri-nitrate, the slight deficiency of nitrogen being possibly due to the presence

of traces of impurities (oxidised derivatives of glycerine) irremovable by the water with which the nitroglycerine was washed.

We have also estimated the nitrogen in other samples of nitroglycerine, prepared with different proportions of acid, in order to ascertain whether a difference in the method of preparation causes any corresponding difference in the composition of the liquid. The results show that it is not so. In these cases DUMAS'S method was not employed, but a modification of SCHLOESING'S process, which we have found to give equally good results, in spite of the contrary experience of HESS and SCHWAB and of SAUER and ADOR.

The weighed quantity of nitroglycerine was dissolved in absolute alcohol and decomposed by boiling for ten minutes with excess of an alcoholic solution of caustic potash. Water was then added, and the whole of the alcohol was driven off by evaporation; after which the fluid was made up to a given volume, of which a measured portion was taken for experiment. The volume of nitric oxide evolved by the reducing action of the ferrous chloride and hydrochloric acid (the reagents employed in SCHLOESING'S method) was, in each case, compared with the volume of gas obtained under precisely the same conditions of temperature and pressure from a standard solution of pure potassium nitrate, aud also, in certain instances, of pure sodium nitrite; and from these data the percentage of nitrogen was calculated. A correction is, however, necessary, inasmuch as a small portion of the nitrogen is always evolved as ammonia on boiling the nitroglycerine with potash. The amount of this was determined in a preliminary experiment, as follows :—

1·1533 grm. of nitroglycerine was dissolved in 5 c.c. absolute alcohol and a solution of 1·5 grm. of potash in absolute alcohol added, the flask being immediately connected with a modified BOUSSINGAULT'S apparatus and then boiled. After half an hour an equal volume of water was added, and boiling then continued three-quarters of an hour more. The distillate was received into standard acid; and, at the end of the operation, this was titrated with standard soda. By this means it was found that ·0053 grm. of ammonia had been evolved; so that nitroglycerine loses nitrogen during decomposition with potash to the extent of 0·38 per cent. of its weight. This amount was, therefore in each case, added to the percentage of nitrogen found by SCHLOESING'S method.

In the following table the letters in the second column refer to the various samples of nitroglycerine employed. A detailed description of their manufacture will be found in the preceding paper,* where they are lettered in the same order. Experiment IX. was made with nitroglycerine obtained from a NOBEL'S dynamite cartridge by displacement with water and desiccation over the water-bath.

* "A Contribution to the Chemistry of Nitroglycerine," by MATTHEW HAY.

No. of Experiment.	Nitroglycerine Employed.	Percentage Nitrogen found.	Corrected for loss of NH_3.	Percentage Calculated.
I.	A	17·77	18·15	
II.	A	17·47	17·85	
III.	A	17·76	18·14	
IV.	B	17·76	18·14	
V.	C	17·76	18·14	18·50
VI.	F	17·41	17·79	
VII.	J	17·81	18·19	
VIII.	N	17·73	18·11	
IX.	Nobel's	17·77	18·15	

These figures agree closely not only with each other, but with those obtained by us by DUMAS's method. Our analyses already given prove nitroglycerine to be glyceryl tri-nitrate : these analyses render it highly probable that it is invariable in composition, and that therefore the statements of some previous investigators, particularly those of HESS, are erroneous. If nitroglycerine at any time does contain the lower nitrates of glyceryl, it is probably owing to the nitroglycerine having been very imperfectly washed in the process of its manufacture. Nitroglycerine is only very slightly soluble in water; glycerine is freely soluble in water; and, reasoning from chemical analogies, it is highly probable that the intermediate nitrates possess intermediate degrees of solubility, which will readily permit of their removal by an ordinarily complete washing of the nitroglycerine with water, but may allow only of their partial removal if a limited quantity of water is used. According, however, to the published description of the various commercial processes for the preparation of nitroglycerine, the washing appears to be sufficiently thorough to remove the lower nitrates; for the amount of washing necessary to remove traces of the free acid used in the manufacture of nitroglycerine is certainly quite sufficient to dissolve out the lower nitrates.

VII.—*Report on the* Tunicata *collected during the Cruise of H.M.S. "Triton" in the Summer of* 1882. By W. A. Herdman, D.Sc., Professor of Natural History in University College, Liverpool. (Plates XVI. to XX.)

(Read 16th July 1883.)

This collection was sent to me for examination some months ago by Mr Murray. It may be conveniently divided into two very natural groups:—

1. Ascidiacea, including the forms dredged or trawled from the bottom of the sea.
2. Thaliacea, including the free-swimming pelagic forms captured by the tow-net at or below the surface.

The small group of Ascidiacea contains no Compound Ascidians, and only two* of the four families of Ascidiæ Simplices known are represented in it. The one of these families (the Cynthiidæ) is represented by a single species only, while the other (the Ascidiidæ) contains the remaining three species, referred to the two genera *Ascidia* and *Ciona*. One of those species of Simple Ascidians (*Ascidia tritonis*) is new to science, the other three are well-known British forms.

This little collection of Ascidiacea is chiefly interesting (1) on account of the depths at which the specimens were procured, and (2) on account of the locality being one in which the Ascidian fauna had not been previously investigated. *Ascidia tritonis*, though a new species, is not in any way aberrant or strikingly peculiar, and hence, as far as the Simple Ascidians of the collection go, the region explored by the "Triton" may readily be regarded as an extension of the British fauna.

The second group—the Thaliacea—is a very considerable collection, as may be seen from the following list of the different localities. The most remarkable circumstance in regard to it is that, with the exception of two specimens of *Salpa*, the whole series is composed of one species, *Doliolum denticulatum*, of which between five and six thousand specimens were collected.

List of "Triton" Thaliacea.

1882.	
August 3rd—4th.	Surface. *Doliolum denticulatum*, about 100 specimens, 1 small one (2 mm. long).
„ 4th.	Tow-net at a depth of 12 fathoms. *Dol. denticulatum*, 8 specimens, in absolute alcohol.
„ 4th—5th.	Tow-net at a depth of 12 fathoms. *Dol. denticulatum*, about 1000 specimens; and 1 specimen of *Salpa runcinata* (aggregate form).

* See "Postscript," page 114.

August 5th (Station 2). Nets at the weights and trawl, 530 fathoms. *Dol. denticulatum*, about 1000 specimens; also 6 specimens in absolute alcohol.

„ 7th. Surface. *Dol. denticulatum*, about 30 specimens.

„ 7th—8th. Surface. „ 3 specimens, in absolute alcohol.

„ 8th. Surface. „ 20 specimens.

„ 9th. Tow-nets at a depth of 100 to 150 fathoms. *Dol. denticulatum*, 60 specimens; also 20 in absolute alcohol.

„ „ Tow-nets at trawl at a depth of 327 to 430 fathoms. *Dol. denticulatum*, 20 specimens.

„ 13th—30th. Surface to 40 fathoms. *Dol. denticulatum*, 9 specimens.

„ 18th. Surface. *Dol. denticulatum*, 1 specimen; and 1 specimen of *Salpa runcinata* (solitary form).

„ 20th. Surface. *Dol. denticulatum*, 1 large and 3 small (2–3 mm. long) specimens.

„ „ Tow-net at a depth of 40 fathoms. *Dol. denticulatum*, about 50 specimens.

„ „ Tow-net at a depth of 300 fathoms. *Dol. denticulatum*, about 40 specimens.

„ „ Tow-nets with 400 fathoms of line out. *Dol. denticulatum*, 75 specimens.

„ „ Tow-nets at a depth of 400 fathoms. *Dol. denticulatum*, 12 specimens.

„ 21st. Surface. *Dol. denticulatum*, 1 specimen, stained brown.

„ „ Tow-net at a depth of 40 fathoms. *Dol. denticulatum*, about 50 specimens.

„ „ Tow-nets from surface to 400 fathoms. „ „ 80 „

„ „ „ at a depth of 600 „ „ „ 50 „

„ 22nd. Tow-nets between surface and 40 „ „ 25 specimens.

„ 22nd—23rd. Surface, at night. „ 75 „

„ 24th. Tow-nets at a depth of 40 fathoms. „ 1 specimen.

„ 28th. Surface. „ 50 specimens.

„ „ Surface down to 40 fathoms. „ about 40 specimens.

„ „ Tow-nets at a depth of 40 fathoms. „ 30 specimens.

„ 29th. Surface. *Dol. denticulatum*, 28 specimens, in osmic acid and absolute alcohol.

„ „ „ about 100 „ picric „

„ „ „ „ 180 „ osmic „

„ „ „ „ 150 „ chromic „

„ „ Tow-net at a depth of 5 to 10 fathoms. *Dol. denticulatum*, about 1200 specimens.

„ „ Tow-nets at a depth of 10 fathoms. *Dol. denticulatum*, about 150 specimens, in chromic acid.

„ „ Tow-nets at a depth of 13 fathoms. *Dol. denticulatum*, 1 specimen, in chromic acid.

„ „ Tow-nets at a depth of 12 fathoms. *Dol. denticulatum*, about 100 specimens, in picric acid.

„ „ Tow-nets at a depth of 20 fathoms. *Dol. denticulatum*, about 100 specimens.

„ 30th. „ „ 40 „ „ 200 „

„ „ Tow-nets with 400 fathoms of line out. *Dol. denticulatum*, about 130 specimens.

„ „ Tow-nets at weights (Station 12), 580 fathoms. *Dol. denticulatum*, 50 specimens.

„ 31st. Surface. *Dol. denticulatum*, 100 specimens.

„ „ Surface down to 40 fathoms. *Dol. denticulatum*, about 100 specimens, one of them small (3 mm. long).

„ „ Tow-net at trawl (Station 13), depth 570 fathoms. *Dol. denticulatum*, 20 specimens.

Also, obtained during the cruise of the "Knight Errant":—

August 10th, 1880, From a depth of 20 fathoms. *Salpa zonaria*, 10 specimens.

The localities of most of these dates, namely, 7, 7–8, 8, 9, 18, 20, 21, 29, and

30, are over the "Wyville-Thomson" ridge, 7, 7–8, 8, 9, and 30 being towards the NW. end, and 18, 20, 21, and 29 near the centre. 22 and 22–23 are situated in the "cold area" near its southern end; while 24, 28, and 31 are in the "warm area" near the SE. end of the ridge. 3–4, 4, 4–5, and 5 are between the island of Rona and the southern end of the ridge.

Order I.—ASCIDIACEA.

Family Cynthiidæ.

Polycarpa pomaria, Savigny (Pl. XVII. figs. 5 and 6).

I have referred a small specimen from Station 3 to this widely distributed and apparently highly variable species. I have not examined a sufficient number of specimens to be able to say much as to the range of variation from my own experience; but from a comparison of the descriptions of other investigators, it is obvious that this is one of those interesting forms out of which it is possible to make either one or half a dozen "species," according to the state of one's critical faculties. Traustedt* describes it as *Styela pomaria*, and gives as synonymous *Cynthia pomaria*, Sav., *C. coriacea*, Alder, *C. tuberosa*, Macgill, and *Polycarpa varians*, Heller; while Heller† suggests that *Cynthia sulcatula* and *C. granulata* of Alder may also be varieties merely.

There can be little doubt that Savigny's *Cynthia polycarpa* and *C. pomaria* are merely varieties of the one species now known as *Polycarpa pomaria*, Sav. (=*P. varians*, Heller), and *Cynthia tuberosa* of Macgillivray is certainly the same species; while Alder's *Cynthia sulcatula* and *C. granulata* may possibly be young individuals. But I cannot agree with Traustedt and Heller in regarding *Cynthia coriacea*, Alder and Hancock, as another variety. The description in Alder's Catalogue‡ states (1) that the ovaries are large and white, and line the mantle with cylindrical convolutions, and (2) that the branchial sac has about ten longitudinal folds, two important characters either of which would be sufficient evidence to exclude the species from the genus *Polycarpa*, while the second alone, if "about ten" may be taken as meaning more than eight, cuts it off even from the sub-family Styelinæ.

The Triton specimen, which is a small one (2 cm. in length, 1·6 cm. dorso-ventrally, and 1·2 cm. in thickness), was trawled at Station 3 (8th August 1882, at the NW. end of the Wyville-Thomson ridge, and north of the "warm area," bottom s. sh.) from 87 fathoms. Viewed from the side, it is rudely quadrate

* *Oversigt over de fra Danmark og dets nordlige Bilande kjendte Ascidiæ Simplices. Vidensk. Meddel, Nat. For.*, Kjöbenhavn, 1880, p. 415.

† *Untersuchungen über die Tunicaten des Adriatischen und Mittelmeeres*, Abth. iii. p. 19, Wien, 1877.

‡ Cat. Mar. Moll. Northumb. and Durham, *Trans. Tynes. Nat. Field Club*, vol. i. 1850.

rather than hemispherical in outline, the anterior end being truncated and almost as broad as the base of attachment. The most projecting point of the anterior end is placed midway between the two apertures, which are far apart, and distinctly upon the right side of the extremity (see Pl. XVII. fig. 5). Probably on account of extreme contraction, they are also sessile, rather inconspicuous, and irregularly lobed.

The test is thick, strong, and leathery; greyish-white on the outer surface, and white in section. At the posterior end it has several root-like prolongations from 1 to 1·2 cm. in length. The mantle is thick, strongly muscular, and closely united to the inner surface of the test.

The branchial sac has eight very prominent folds, four upon each side. The two dorsal folds on each side are more closely placed than the ventral ones, and the clear spaces bordering the endostyle are considerably wider than those beside the dorsal lamina. As the branchial sac of this species has never, so far as I am aware, been figured, I give a view (Pl. XVII. fig. 6) from the inside of a part showing two folds and the interspace in their natural relations, while at the right-hand side another interspace is represented as more exposed by the removal of the next fold. The sac is a very thick one, the folds being prominent, the internal longitudinal bars numerous, and the stigmata comparatively small. Occasional wider transverse vessels occur; in some places (see fig., *tr*) they alternate regularly with three smaller ones (*tr'*). Delicate membranes dividing the meshes are only present here and there (*tr''*). At the base of each fold lies a series of large meshes (*mh*), each of which I found contained about six stigmata. HELLER mentions meshes with ten to twelve stigmata each; I found such only in the series adjoining the endostyle.

The simple tentacles are numerous and closely placed. The dorsal tubercle is small and nearly circular in outline, being slightly elongated laterally. The aperture is anterior, and both horns are coiled inwards.

The margin of the anus is expanded, and cleft into a number of blunt processes.

The yellow polycarps and grey endocarps are so numerous as almost completely to hide the inner surface of the mantle.

Family ASCIDIIDÆ.

Ascidia tritonis, n. sp. (Plate XVI.).

External Appearance.—Shape ovate, flattened laterally, attached by posterior half of left side, especially towards the ventral edge; anterior end rather narrower than posterior but blunt. Dorsal edge slightly more convex than ventral. Branchial aperture terminal, sessile, wide, lobes distinct. Atrial

aperture on dorsal edge, halfway from anterior to posterior end, sessile, wide, indistinct lobed. Surface even and soft, but finely roughened all over. Colour greyish-brown.

Test soft, cartilaginous, not stiff; thin on right side, much thicker on left, especially at the area of attachment, where it increases to 1·5 cm.; smooth and glistening on inner surface; clear and transparent in section. Vessels not conspicuous.

Mantle.—Shape long and narrow; siphons long, especially atrial, which is placed nearly halfway down the dorsal edge; musculature strong on right side, almost absent on left, where the mantle is thin and membranous; sphincters moderately developed.

Branchial Sac rather delicate and not plicated. Transverse vessels alternately larger and smaller, the larger ones with broad membranes hanging from them. Internal longitudinal bars narrow, bearing large curved papillæ at the angles of the meshes. Stigmata long and narrow, usually five in each mesh.

Dorsal Lamina narrow, slightly ribbed transversely, and toothed on the margin; double for a short distance at the anterior end.

Tentacles numerous, of several sizes, some very long (up to 1·5 cm.), stout at the base.

Dorsal Tubercle small, irregularly ovate in outline, aperture anterior, horns not coiled.

Alimentary Canal not large, placed on the left side of the body about the middle. Œsophageal aperture two-thirds of the way down the dorsal edge of the branchial sac; stomach irregularly pyriform; intestine rather wide, and forming a narrow loop.

Genitalia in intestinal loop. Spermatic vesicles extending over the greater part of the intestine. Vas deferens wide and prominent, running along the posterior and dorsal side of the rectum towards the atrial aperture.

Three large specimens and one small one of this new species of *Ascidia* were obtained in the second haul of the dredge at Station 13 (31st August 1882, in the centre of the "warm area"), from a depth of 570 fathoms, bottom ooze. All of the specimens were more or less incrusted, especially upon the left side, with fragments of sponges and worm tubes; one of them had a few specimens of a small Tubularian zoophyte adhering, while the smallest individual had several specimens of *Anomia ephippium* attached to its test.

The largest specimen is 13·5 cm. in length and 8 cm. in breadth, the smallest 5 cm. in length and 3 cm. in breadth. The remaining two are 9·5 cm. and 10·5 cm. respectively in length, while both measure 6·5 cm. across at the widest point. In general shape, and especially in the position of the atrial aperture

(see Pl. XVI. fig. 1), this species shows resemblances to *Ascidia lata** and *Ascidia meridionalis*,† but it differs greatly from both these species in internal structure.

The shape of the body when the test is removed (Pl. XVI. fig. 3) is remarkable on account of its great antero-posterior elongation, and the position of the stomach and the intestine so far from the posterior end. The appearance presented by the body when seen from the left side suggests that this peculiar relation is caused by the branchial sac having extended posteriorly beyond the stomach.

The muscular pad at the base of the branchial siphon, from the lower edge of which the tentacles spring (Pl. XVI. fig. 6), is very strong. The tentacles are large, and so numerous that their bases touch.

The dorsal tubercle (Pl. XVI. fig. 6) is peculiar, inasmuch as the left horn is bifurcated; however, this is very possibly merely an individual variation.

With the exception of *Ascidia meridionalis*, obtained during the "Challenger" expedition at 600 fathoms, off the south-eastern coast of South America, the present species was found at the greatest depth from which the genus *Ascidia* has been recorded.

Ascidia virginea, O. F. Müller (Pl. XVII. figs. 3 and 4).

(=*Ascidia sordida*, Alder & Hancock, Cat. Mar. Moll. Northumb., &c.)

At first sight, and after a hasty examination, I was inclined to consider this specimen as a new species, but after a more careful investigation of its anatomy I prefer to regard it as merely an abnormally-shaped individual of *Ascidia virginea*. If this form should be found to occur with sufficient frequency it might be distinguished as variety *pedunculata*. I remember dredging a similar individual a few years ago in the Firth of Forth, but cannot now find the specimen in my collection.

The body is pyriform, shortly pedunculated, and attached by the posterior end (Pl. XVII. fig. 3); it is slightly compressed dorso-ventrally. The anterior end is narrow, but widens rapidly, especially on the right side; the widest point is reached at a little more than one-eighth of the distance from the anterior to the posterior end. The anterior half is moderately swollen, the posterior half is much narrower, and forms a short stalk. The apertures are both near the anterior end, not distant, sessile, but conspicuously lobed. The surface is rather irregular, but smooth; it is somewhat incrusted by foreign objects. The peduncle is slightly enlarged at its lower extremity to form a disc of

* Herdman on British Tunicata, *Linn. Soc. Jour.*, Zool., vol. xv. p. 277.

† Herdman, Report upon the Tunicata of the "Challenger" Expedition, part i. p. 207.

attachment. The colour is dirty grey. Length, 5 cm.; greatest breadth, 2 cm.; thickness of peduncle, 1 cm.

The test is thin, except at the top of the peduncle, where it is considerably thickened. The peduncle is solid, and formed of test alone. The vascular trunks enter the test at the top of the peduncle.

When the test is removed the body has the appearance usual in *Ascidia virginea*, and the mantle is in a normal condition, strongly muscular on the right side, but thin and weak upon the left.

The branchial sac corresponds in all respects with what I have found in other specimens of the species. It is longitudinally plicated to a slight degree, has strong internal longitudinal bars with no papillæ, and square meshes with five or six stigmata each.

The dorsal lamina is strongly ribbed transversely. The tentacles are numerous, closely packed together, and of several sizes. Those of the first order are long and slender. The dorsal tubercle is simple, and elongated antero-posteriorly. The posterior three-fourths or so is enclosed in the small peritubercular area, and the end is pointed. The aperture is anterior, and the horns are not coiled (Pl. XVII. fig. 4). *Ascidia virginea* is one of the most variable species known, in regard to the shape of the dorsal tubercle.* The present form is rather simpler and more symmetrical than usual, and is peculiar in having the posterior end pointed.

The single specimen was trawled off the Butt of Lewis, 25th August 1882, depth, 40 fathoms.

Ciona intestinalis, Linn. (Pl. XVII. figs. 1 and 2).

Sixteen specimens of this common British species were in the collection sent to me, four of them being preserved in absolute alcohol. They were all obtained by the trawl at Station 3 (8th August 1882, at the north-west end of the Wyville-Thomson ridge, and north of the "warm area," bottom s. sh.) from a depth of 87 fathoms. This is the greatest depth known to me at which this species has been found, but it is quite possible that it may have been obtained in Scandinavian seas, or in the Mediterranean at greater depths, though I have been unable to find records of such instances. The "Triton" specimens are all of fair size, and as some of them are much corrugated it is probable that they were large individuals when alive and expanded.

The tests are more colourless than is usual with shallow water specimens from our own coasts, and have almost none of that dull green tint which may generally be observed even after preservation in spirit. On the other hand,

* See HERDMAN, "On the 'Olfactory Tubercle' as a Specific Character in Simple Ascidians," *Proc. Roy. Phys. Soc. Edin.*, vol. vi. session cx. p. 256, 1881.

the red pigment spots at the branchial and atrial apertures and the pigment on the aggregation of glands at the opening of the vas deferens are as bright and conspicuous as is usual in the living animal. In one of the specimens preserved in absolute alcohol, which was dissected, the inner surface of the test was found to be closely ribbed longitudinally and less conspicuously so transversely. This has been caused by the test having remained attached to the mantle during the contraction of the latter, and having become impressed by the subjacent strongly developed longitudinal muscles.

The papillæ at the angles of the meshes in the branchial sac seemed larger than is usual in the species, and were certainly much larger than those represented by HELLER* from a Mediterranean specimen. In some places their length equalled the space between two neighbouring internal longitudinal bars, so that when laid flat they stretched across the mesh.

I have observed considerable individual variation in the branchial sac of this species. In 1881† I noted a variability in the number of stigmata contained in each mesh, and since then I have met with several other points in which individuals differed. The specimens examined have been from various parts of the British seas—the Firth of Forth on the east; Lamlash Bay, Loch Fyne, and the Sound of Mull on the west; and Poole, Portland, and Dartmouth on the south coast. I have also specimens from the Channel Islands, the Chausey Archipelago, and the coast of Brittany, in addition to those collected by the "Triton" in the North Atlantic.

I have very rarely seen the arrangement figured by HELLER‡ where the meshes are represented as being greatly elongated transversely, and occupied by two rows of extremely short stigmata. Usually the meshes are nearly square, and are divided into two areas by a delicate transverse membrane, which, however, does not generally interrupt the stigmata. This is shown at *tr'* in fig. 2, where the membrane crosses the mesh, while the stigmata extend behind. In the mesh below no transverse membrane is present, while in fig. 1 three are seen, the central one being much the strongest. This last arrangement was found to be very prevalent in the sac of the "Triton" specimen examined. In some specimens the meshes, in place of being square, are considerably elongated longitudinally—the reverse of the variation figured by HELLER—and the contained stigmata are very long and narrow. In this case the meshes are always divided by from one to three transverse membranes.

The papillæ upon the internal longitudinal bars appear liable to considerable variations in their size and arrangement. In some cases they are present only at the angles of the meshes, as shown in the lower part of fig. 2, and are then all of much the same size. Where the meshes are divided there is usually a

* *Untersuchungen über die Tunicaten des adriatischen Meeres*, Abth. ii. Taf. iv. fig. 6, Wien, 1875.
† *Jour. Linn. Soc.*, Zool., vol. xv. p. 332. ‡ *Loc. cit.*

papilla placed at each point of intersection with the median or chief transverse membrane (*tr'* in the figs.) and the internal longitudinal bars. These papillæ are usually rather smaller than those at the angles of the meshes, but in some cases (as is shown in the upper part of fig. 2) the papillæ may be all of the same size. I have found the chief papillæ varying in size from a little less than one-half* the breadth of the mesh to (in the case of the "Triton" specimen) the entire breadth. In fig. 1 the papillæ have been omitted, in order that the transverse membranes might be clearly seen.

Returning to the "Triton" specimen, the margin of the anus was expanded and more deeply indented than is shown in HELLER's figure.† The oviduct was found full of ova, some of which were also discovered in the peribranchial cavity; and the pigmented glands at the aperture of the vas deferens seemed to form a larger and more conspicuous mass than usual.

ORDER II.—THALIACEA.

Both families of this order, the Doliolidæ and the Salpidæ, are represented in the collection.

Family I.—DOLIOLIDÆ.

Doliolum denticulatum, Quoy and Gaimard (Pls. XVIII., XIX., and XX.).

The five or six thousand specimens of *Doliolum* in the collection are, I was astonished to find, all one form, and this I have identified with the sexual generation of *Doliolum denticulatum*.‡ This species was first described and figured by QUOY and GAIMARD, the founders of the genus, in the zoology of the voyage of the "Astrolabe,"§ in 1835. It had been found in the Malay Archipelago near the islands of Amboyna and Vanikoro. Sixteen years later HUXLEY‖ published his observations made upon certain Tunicata during the voyage of the "Rattlesnake." In this paper very considerable additions are made to the knowledge of the structure of *Doliolum*, and the relations in

* In Heller's figure they are about one-fourth of the breadth of the mesh.

† *Loc. cit.*, Taf. v. fig. 8.

‡ As will be pointed out in the following description, there are a number of details, especially in the branchial sac, in which these "Triton" specimens differ from the accounts of *Doliolum denticulatum* given by KEFERSTEIN and EHLERS (*Zoologische Beiträge*, 1861) and by GROBBEN (*Arbeiten aus dem Zoolog. Instit. der Univ. Wien*, 1882). As, however, they agree with those authors' descriptions in the more important anatomical features, and as they could not be referred to any other known species, I prefer to consider them as a variety of *Doliolum denticulatum*. It is improbable that they are an undescribed species, since they are apparently so common in the North Atlantic. *Doliolum denticulatum* is probably rather a variable form.

§ "Voyage de découvertes de l'Astrolabe," Zoologie, T. iii. pt. 2, p. 599; Atlas, Mollusques, pl. lxxxix. figs. 25–28. Paris, 1835.

‖ "Remarks upon Appendicularia and Doliolium," &c., *Phil. Trans.* for 1851, part 2, p. 599, pl. xviii.

which the genus stands to *Salpa* and *Pyrosoma* are pointed out. HUXLEY's specimens had been obtained in the South Pacific between Australia and New Zealand. During the next few years KROHN,* GEGENBAUR,† and LEUCKART‡ worked at the Pelagic Tunicata, but their efforts, and especially those of the two former investigators, were mainly directed towards the elucidation of the remarkably complex life-history of *Doliolum*, and the additions made to the knowledge of the adult structure were comparatively few and unimportant.

KEFERSTEIN and EHLERS,§ during the winter of 1859–60, investigated several Mediterranean forms of *Doliolum*, both as regards their anatomy and life-history. As the chief subject of their observations was *Doliolum denticulatum*, it has been of great advantage to have their description and careful figures with which to compare the "Triton" specimens. No works of importance upon *Doliolum* have appeared since, with the exception of ULIANIN's‖ and GROBBEN's¶ papers, published during the last two years. These are mainly devoted to the development and life-history, which is now almost completely cleared up. GROBBEN, however, treats also of the anatomy and histology, and to his memoir, as well as to that of KEFERSTEIN and EHLERS, I shall have to refer in the following description.

Commencing with the body form, most of the "Triton" specimens are of the characteristic barrel shape (see Pl. XVIII. figs. 1, 2, 3, 4, and 9), some of them (as fig. 9, which was drawn from a specimen obtained August 4–5 from 12 fathoms) being rather wider than others. Some specimens, however (see fig. 10, which represents two specimens obtained on August 5th from a depth of 530 fathoms), are very different in shape, being narrow, elongated, and almost cylindrical. At first I separated out a number of these forms, under the impression that they were a distinct species from the barrel-shaped individuals, but found afterwards, when examining their structure, that the two kinds agreed perfectly in all the details of their anatomy. Since then I have found various intermediate shapes between those shown in figs. 9 and 10, and have consequently no hesitation in considering them all as one species. As a rule, I find it is the specimens from considerable depths, and those which have been closely packed in a tube or bottle, which diverge most from the typical barrel

* "Ueber die Gattung Doliolum," &c., *Archiv für Naturgeschichte*, 1852, p. 53.

† "Ueber die Entwicklung von Doliolum," *Zeitschrift für wissensch.*, Zoologie, 1853, Bd. v. p. 13; and "Ueber die Entwicklungscyclus von Doliolum," &c., *Zeitschrift für wissensch.*, Zoologie, 1855, Bd. vii. p. 283.

‡ *Zoologische Untersuchungen*, Heft ii., "Salpen und Verwandte," Giessen, 1854.

§ *Zoologische Beiträge*, iii., "Ueber die Anatomie und Entwickelung von Doliolum," Leipzig, 1861.

‖ "Ueber die embryonale Entwicklung des Doliolum," *Zoologischer Anzeiger*, iv. No. 92, p. 472, and No. 96, p. 575, 1881; also "Zur Naturgeschichte des Doliolum," *Zoologischer Anzeiger*, v. p. 429 and p. 447, 1882.

¶ "Doliolum und sein Generationswechsel," &c., *Arbeiten aus dem Zoolog. Instit. der Univ. Wien*, &c., t. iv. h. 2, 1882.

shape, hence it is probable that the abnormal form is due either to the animal not having been killed suddenly enough or to imperfect preservation. All of the "Triton" specimens, with the exception of the five small ones mentioned in the list on page 93, are between 6 mm. and 12 mm. in length, and most of them measure 1 cm. This size is apparently much greater than that of Mediterranean specimens, as GROBBEN speaks of his as being about 2·5 mm., while KEFERSTEIN and EHLERS figure one 3 mm. in length.

Most of the specimens are in ordinary rectified spirit, while a few have been treated in each of the following methods:—

1. Preserved in absolute alcohol.
2. Put first into chromic acid solution and then into absolute alcohol.
3. Preserved in a saturated solution of picric acid.
4. Put first into solution of osmic acid and then into absolute alcohol.
5. Put first into solution of picric acid and then into absolute alcohol.
6. Preserved in solution of chromic acid.

These specimens were all in excellent condition for examination, and the different methods appear to give almost equally good results. Perhaps the best preparations for most histological points were obtained from the specimens preserved in chromic acid by thoroughly washing in alcohol, staining in picro-carmine, and mounting in Farrant's solution; while for some few special points the specimens preserved in osmic acid solution and absolute alcohol excelled.

The test is almost absent, being represented merely by a delicate structureless layer over the ectoderm, which covers the surface of the mantle. The mantle contains the muscular bands or hoops, which, in this form, are eight in number (m^1 to m^8 in the figs.). The first and last of these bands form sphincters for the apertures, and usually appear to terminate the body anteriorly and posteriorly, as shown in Plate XVIII. fig. 4, the delicate denticulated margins of the branchial and atrial apertures being almost invariably turned in or directed across the opening. This denticulated margin was turned out in the chromic acid specimens examined, and was more perfectly preserved than in any of the others. It is divided into twelve lobes around the branchial aperture and ten around the atrial. The muscle bands are composed of very long non-striped fibres, closely and regularly placed, as shown in Plate XVIII. fig. 6. Sometimes, as in fig. 5 (from a picric acid specimen), the fibres are thrown into undulations.

The wide branchial aperture leads into the branchial siphon, which, as there is no diaphragm and no circlet of tentacles, may be considered as extending back to the peripharyngeal band. This band, in all the specimens which I have examined, runs in most of its course between the 2nd and 3rd muscle bands, or in the 2nd intermuscular space (Pl. XVIII. fig. 11, *p.p*), and marks the anterior

end of the branchial sac, which extends back usually to between the 5th and 6th muscle bands. GROBBEN, however, describes and figures* the peripharyngeal band as lying in the 1st intermuscular space. KEFERSTEIN and EHLERS also represent† the branchial sac as extending anteriorly into the 1st intermuscular space, an arrangement which I have been unable to find in the "Triton" specimens.

The arrangement of the stigmata is as follows:—A series commences on each side of the median dorsal line, close behind the 3rd muscle band (see Pl. XVIII. figs. 8 and 11, *sg*), and extends posteriorly for a variable distance —usually to about the 6th muscle band. The stigmata in this series differ greatly in size among themselves. The most anterior one is very short—in fact, almost circular. The next three or four increase rapidly in length till the level of the nerve ganglion (*n.g.*) is reached, and then the increase becomes less marked. Towards the posterior end there is a slight diminution in size. Considered as a whole, the two series of stigmata diverge somewhat posteriorly, so that the space between them in the dorsal middle line is narrow in the 3rd intermuscular space, the region of the ganglion, but widens posteriorly (Pl. XVIII. fig. 11). As a result of this arrangement, when the branchial sac is seen from the side, the dorsal series of stigmata appear to slope downwards and backwards from the region of the ganglion (see Pl. XVIII. fig. 4). There is also a series of stigmata upon each side of the ventral median line. These, however, do not extend so far anteriorly as the dorsal series do. They commence behind the 4th muscle band, near the posterior extremity of the endostyle, and extend backwards, increasing in length rapidly at first, and then maintaining their size till they come to the sides of the œsophageal aperture. Here they commence to curve dorsally, and then towards each other, finally uniting in the dorsal middle line, usually near the 6th muscle band, so as to form a curve surrounding the membranous area in which the œsophageal aperture is placed (see Pl. XIX. fig. 10, *sg*).

The membranous side wall of the branchial sac is very wide anteriorly, where it extends from the endostyle almost to the ganglion dorsally. In the 4th intermuscular space it is encroached upon by the development of the ventral series of stigmata, and as it is traced posteriorly from this point, it becomes narrower and narrower, till finally it merges upon each side into the median dorsal area through the failure of the dorsal stigmata. The exact number of stigmata in the different series varies of course according to the size of the individual. In mature specimens there are usually from thirty to fifty in the dorsal row on each side, and about thirty as an average in each ventral series.

* *Loc. cit.*, p. 13, woodcut, and pl. i. fig. 1, *wb*.
† *Zoologische Beiträge*, pl. ix. figs. 1 and 2.

A glance at Plate IX. of KEFERSTEIN and EHLERS' work suggests that the specimens there figured may have been young, and the number of stigmata shown (thirteen to fifteen in the dorsal row) is just about the number present in the smallest "Triton" specimens (2 mm. long). Perhaps this may also account for the great anterior extension of the dorsal rows of stigmata which are represented as reaching in front of the 2nd muscle band, while in the "Triton" specimens they were never seen in front of the 3rd (see Pl. XVIII. figs. 8 and 11). The ventral band, containing fifteen stigmata, is shown by KEFERSTEIN and EHLERS extending to the front of the 3rd intermuscular space, while in all the specimens which I have examined, it has terminated some place in the 4th intermuscular space. GROBBEN* speaks of forty-two as the largest number of stigmata upon each side which he observed, KEFERSTEIN and EHLERS† say that the number may vary from twenty-six to forty-three, while the usual number in the "Triton" specimens was about seventy! GROBBEN also describes and figures‡ the series of stigmata as extending exactly one intermuscular space further anteriorly than I found to be the case. As they appear always to terminate posteriorly in the neighbourhood of the 6th muscle band, it is obvious that there must be a greater number of stigmata in each intermuscular space in the "Triton" specimens than in those from the Mediterranean, and a comparison of my figures on theone hand, with those of GROBBEN and of KEFERSTEIN and EHLERS on the other, shows that this is the case.

The bars separating the stigmata are covered in the usual manner with ciliated cells placed in such a position that the cilia project across the stigmata. These cells are not placed in a single row, as a surface view of the branchial sac such as that shown in fig. 2, Plate XIX. might lead one to imagine, but are placed in groups of four or five elongated cells placed closely side by side§ (see Pl. XIX. fig. 3). This arrangement can only be made out by viewing the bar upon which the cells are placed from the interior of the stigma. An osmic acid preparation showed with a Zeiss $\frac{1}{12}$-in. oil immersion objective that these cells were nucleated and nucleolated, and had a striated band upon the free edge, from which the cilia project (Pl. XIX. fig. 4). At the rounded ends of the stigmata the ciliated cells are very numerous, forming many rows. They also change their character (see Pl. XIX. fig. 2), and become cubical, spherical, or polygonal in shape.

The endostyle is always a well-marked feature in the ventral middle line of the branchial sac. It extends from midway between the 2nd and 3rd muscle bands anteriorly (Pl. XVIII. figs. 7 and 11, *en*) to somewhere in the

* *Loc. cit.*, p. 16. † *Loc. cit.*, p. 57. ‡ *Loc. cit.*, p. 16, and pl. i. fig. 1.

§ GROBBEN has figured a similar arrangement in the case of the asexual forms of the same species (*Loc. cit.*, pl. v. figs. 34, &c.).

4th intermuscular space posteriorly. KEFERSTEIN and EHLERS represent it as extending rather further anteriorly, but terminating at the 4th muscle band posteriorly; while in GROBBEN's figures it commences as in mine, but terminates in the 3rd intermuscular space. At its anterior extremity the endostyle is joined by the ventral ends of the two peripharyngeal bands (see Pl. XVIII. figs. 7 and 11), while posteriorly it is continued into a membrane with a free projecting edge which runs backwards over the heart, and then round the left hand side of the œsophageal aperture (Pl. XIX. fig. 10, *mb*). The histology of the endostyle has been minutely described by GROBBEN (*loc. cit.*).

The prebranchial zone, the region anterior to the peripharyngeal band, is covered by squamous epithelium. In osmic acid preparations the protoplasm in these cells is found to have become contracted and aggregated around the distinct nuclei, so as to present the appearance, shown in Plate XIX. fig. 6, of stellate cells united by their processes to form a network.

On the surface of the peripharyngeal band this epithelium has become modified into long fusiform cells (Pl. XIX. fig. 5) all placed with their long axes directed along the band. When not so highly magnified, or not stained properly, they give rise to the appearance shown in Plate XVIII. fig. 13. The dorsal ends of the two peripharyngeal bands meet, but at this point they are twisted round so as to form a double spiral towards the right, the left hand band performing one and a half turns, and the right a single turn only. This arrangement is shown in figs. 8, 11, and 12 on Plate XVIII., and at once suggests the form of the dorsal tubercle found in a similar position in the Ascidiacea. That organ is represented, however, in *Doliolum*, not by the curved dorsal part of the peripharyngeal band which has been described, but by the anterior end of the deeply funnel-shaped depression indicated by *n.a* in figs. 8 and 12.*

The part of the prebranchial zone which is enclosed by the dorsal spirals of the peripharyngeal band has its epithelium modified into large polygonal cells, the outlines and nuclei of which are strongly marked. In the preparation from which fig. 7 on Plate XIX. was drawn, the protoplasm in most of the cells was aggregated around the nucleus in a stellate form.

The nerve ganglion is placed in the mantle, and indicates the median dorsal line. It is small, but very distinct from its opacity. It is usually rudely cubical or nearly spherical in shape, and gives off four large nerve trunks, two at its anterior and two at its posterior angles, besides smaller nerves between. It usually lies a short distance behind the 3rd muscle band, as shown in figs. 8

* Possibly the cavity (*n.a* in the figures) represents merely the opening of the duct from the neural gland into the dorsal tubercle of the Ascidiacea, while the spirals (*d.t*, in Pl. XVIII. fig. 11) indicate the sense-organ, which I believe the dorsal tubercle to have formerly been (see *Proc. Roy. Soc. Edin.*, p. 144, 1882–83.

and 11 on Plate XVIII., but may be further back as represented by KEFERSTEIN and EHLERS in their pl. ix. fig. 1. It may advance forward, so as to touch the 3rd muscle band (see Pl. XIX. fig. 1), but is never found outside the 3rd intermuscular space.

The ganglion is very opaque, and it is difficult to make out its constitution. Fig. 8 on Plate XIX. shows its anterior end with four nerves, two large and two small, arising from it. GROBBEN * has apparently not noticed the smaller pair (Pl. XIX. fig. 8, *n'*), but he describes a median anterior nerve which I could not find in any of my specimens, unless it be the nerve shown at *n* in Plate XVIII. fig. 12, which is drawn from an individual having apparently only three anterior nerves. As in other Tunicates, where the matter has been investigated, the nerve cells are all in the outer layers of the ganglion, and the centre is formed of a mass of delicate interlacing fibres and granular matter. Fig. 12, Plate XIX., shows this arrangement well. The nerve cells are ovate, unipolar, bipolar, or multipolar, rarely the latter. They are finely granular, and have distinct nuclei and nucleoli (see Pl. XIX. fig. 13).

On the ventral surface of the ganglion there lies a dark mass which must be the neural gland, but of which I was unable to make out the structure definitely. It gives rise anteriorly to a very delicate duct which runs directly forwards to open at the prebranchial zone into the funnel-shaped depression mentioned above (see Pl. XVIII. figs. 8 and 12). This duct is wide where it emerges from below the ganglion, and its wall is formed of distinct polygonal cells (see Pl. XIX. fig. 8 *n.d*). It rapidly narrows, however, as it runs forwards, and the cell elements lose their distinctness, so that in the part immediately in front of the 3rd muscle band (Pl. XVIII. fig. 8, *n.d*) it is very difficult to make out any structure in the wall. In front of this point it again becomes more distinct, and the cells vary from fusiform to squamous in their character (Pl. XIX. fig. 9, *n.d*) up to the point where the duct joins the funnel-shaped depression.

The length of this neural duct varies with the positions of the ganglion and of the aperture in the prebranchial zone. The normal arrangement is shown in figs. 8 and 11, Plate XVIII., while in fig. 1, Plate XIX., it is abnormally short, on account of the unusual position of the ganglion. The aperture in the prebranchial zone is always placed in the median dorsal line upon the most anterior point of the spirals formed by the peripharyngeal band, and therefore in the 2nd intermuscular space. GROBBEN and also KEFERSTEIN and EHLERS figure it in the 1st intermuscular space, an arrangement which I have never seen. Although the peripharyngeal bands encroach upon the 1st intermuscular space at the two sides (see Pl. XVIII. fig. 11), they always, in the specimens which I have examined, dip posteriorly at the ventral and dorsal

* *Loc. cit.*, p. 9.

ends, and hence the anterior end of the endostyle and the dorsal spirals come to be situated in the 2nd intermuscular space.

The aperture in the prebranchial zone is small, and leads into a funnel-shaped cavity continuous with the neural duct (Pl. XIX. fig. 9). At the posterior narrower end of this cavity, the flat cells lining the duct become gradually cubical and then low columnar, and bear each a long cilium which projects into the centre of the cavity, and is directed posteriorly. This funnel-shaped cavity is apparently merely the aperture of the neural duct. I have searched in vain for any trace of a sensory apparatus. In several specimens I have succeeded in tracing one of the smaller nerves given off from the anterior end of the ganglion in its entire course forwards (see Pl. XVIII. fig. 12, *n*). It runs alongside the duct and close to it, but passes the funnel-shaped cavity upon its left side without giving off any branch, and continues its way anteriorly to supply the lobes around the branchial aperture.

The heart is situated on the ventral surface of the posterior end of the branchial sac, just between the termination of the endostyle and the œsophageal aperture and in the posterior part of the 4th intermuscular space (Pl. XIX. fig. 10, *h*). In chromic acid specimens the transverse muscle bands of the wall of the heart were well shown (see Pl. XIX. fig. 11), but each band appears to me to be composed of a large number of very fine fibres placed side by side, and not of one fibre only as supposed by KEFERSTEIN and EHLERS.*

The alimentary canal, omitting the pharynx or branchial sac, which has been already considered, consists of œsophagus, stomach, and intestine, and forms a curved tube, lying mainly in the 5th and 6th intermuscular spaces (Pl. XVIII. fig. 4).

The œsophageal aperture is placed at the posterior end of the branchial sac in the middle line, and nearer to the ventral than to the dorsal surface. It lies in the membranous area prolonged back from the region around the posterior extremity of the endostyle (Pl. XIX. fig. 10), and is surrounded laterally and dorsally by the posterior end of the ventral series of stigmata. This is a notable point, since it is usual in the Ascidiacea for the œsophageal aperture to be placed on the dorsal edge of the sac, and invariably so amongst Ascidiæ Simplices, in some of which it is placed nearer to the anterior than to the posterior end of the dorsal edge.

The œsophageal aperture is surrounded by a membranous rim, which on its left anterior edge is continued forwards to join the posterior extremity of the endostyle, while at its other end, after surrounding the aperture (see Pl. XIX. fig. 10, *mb*), it is continued as a spiral ridge into the cavity of the œsophagus. The œsophagus is short, and leads downwards and backwards to the anterior end of the large irregularly quadrangular stomach (Pl. XX. fig. 1, *st*). From

* *Loc. cit.*, p. 58.

the posterior end of this the short curved intestine emerges. The stomach lies in the 5th intermuscular space, and the intestine runs backwards till it almost or quite reaches the 7th muscle band, and then turns dorsally and to the right, and finally runs forwards to terminate in the anus placed in the 5th intermuscular space, over the stomach (Pl. XVIII. fig. 4). According to KEFERSTEIN and EHLERS the anus is situated at the posterior part of the 5th intermuscular space, or upon the sixth muscle band, while according to GROBBEN it lies in the 6th intermuscular space. HUXLEY figures it in the fifth intermuscular space. The epithelium lining the intestine is polygonal in surface view (Pl. XX. fig. 4) and very distinctly nucleated. In the wall of the stomach the cells are columnar and more darkly coloured.

Two glandular systems, which seem to be quite distinct, are found in connection with this alimentary canal. First, along the ventral surface of the stomach, especially towards the pyloric end, and more or less scattered over the first portion of the intestine, may be found masses of rather darkly coloured glandular-looking cæca (see Pl. XX. fig. 1, *gl*). These branch and apparently anastomose occasionally, forming rude networks, but the branches are short and stout, and the meshes small and irregular. No duct or opening into the alimentary canal was visible. With a higher magnification the cæca present somewhat the appearance shown in Plate XX. fig. 5—masses of cells rounded or polygonal in outline, but rarely angular, having small indistinct nuclei and granular cell-contents. These clumps of branched cæca have apparently not been noticed previously, as I find nothing in the published descriptions and figures which could represent them.

The second glandular apparatus is the system of fine clear-walled tubules ramifying over the intestine, which was first pointed out in *Doliolum* by HUXLEY,* and has since been more or less completely described by LEUCKART, GEGENBAUR, KEFERSTEIN and EHLERS, and GROBBEN. It has also been recently investigated by CHANDELON† in *Perophora* and *Salpa*, where it has very much the same arrangement as in *Doliolum*. CHANDELON comes to the conclusion that the system can be compared neither with a kidney nor a liver, but that it is probably a digestive gland of some kind.

In the specimens which I examined this system appeared generally well developed, although it was sometimes difficult to make out, owing to the opacity of the alimentary canal caused by its food contents. In Plate XX. fig. 1, *d* indicates the duct of this system, which is a clear-walled, almost transparent vessel, entering the pyloric end of the stomach. From this point it may be traced upwards and backwards (Pl. XX. fig. 1, represents a specimen

* *Phil. Trans.*, 1851.

† "Recherches sur une annexe de tube digestif des Tuniciers," *Bulletins de l'Academie Royale de Belgique*, 2me ser. t. xxxix. No. 6, 1875.

in which the intestine has been turned *ventrally* so as to expose the whole alimentary system) to about the middle of the intestine. At this point the duct divides, and its two branches run over the wall of the intestine, subdividing as they go. The twigs branch freely and sometimes anastomose (Pl. XX. fig. 3). Many of them end in short cæcal projections, and in some cases these are enlarged to form terminal knobs (see Pl. XX. fig. 3, *c*), which may contain irregularly rounded bright bodies (concretions ?) similar to those described by CHANDELON in *Perophora*.

The wall of the main duct is lined by regularly arranged fusiform cells placed with their long axes parallel to the length of the duct (Pl. XX. fig. 2). The tubules on the intestine are lined by flattened epithelium bulging into the lumen where the nuclei occur, and enlarged into cubical cells in the terminal knobs.

The apertures of the reproductive organs lie at the posterior end of the body behind the alimentary canal, and usually in the 6th intermuscular space. All the "Triton" specimens of *Doliolum denticulatum* examined belong to the sexual generation, KEFERSTEIN and EHLERS' "generation A," and have both male and female organs well developed.

The ovary is an ovate mass placed usually in front of the 7th muscle band (Pl. XX. fig. 7, *ov*), but occasionally behind it (Pl. XX. fig. 6, *ov*). Ova of different sizes were almost always distinctly visible in it (Pl. XX. fig. 1, *g*, and fig. 13, *ov*). It opens on its dorsal edge into the atrial cavity.

The testis, as HUXLEY* first correctly described, is in the form of a greatly elongated tube, usually nearly as long as the body, terminating posteriorly on the anterior face of the ovary, and extending forwards for a variable distance with rather an irregular course (Pl. XX. figs. 6, 7, &c., and Pl. XVIII. figs. 1–4). At its posterior end, where it abuts against the ovary, it turns dorsally, forming a tube which may be called the vas deferens, and opens into the atrial cavity (Pl. XX. figs. 13 and 14, *v.d.*).

The anterior end of the testis is very variable. KEFERSTEIN and EHLERS state that it may terminate any place between the 3rd and the 1st intermuscular space, and they figure it at the posterior end of the 3rd in one case and the anterior end of the 4th in another. GROBBEN states that it extends forward to the 4th muscle band, while HUXLEY figures it as reaching nearly to the 1st. In most of the specimens which I have examined the anterior end is placed close to the 2nd muscle band, as shown in Plate XX. figs. 6 and 9. No previous investigators, so far as I am aware, either describe or figure the extraordinary variability in form of this anterior end of the testis. A glance at figs. 6, 7, 8, 9, 10, and 11 on Plate XX. shows the extent of this variability. In fig. 6 the tube becomes rapidly smaller opposite the 3rd muscle band,

* *Phil. Trans.*, 1851, part ii. p. 602.

and, after a short undulating course as a very fine tubule, enlarges into a pear-shaped dilatation extending to the 2nd muscle band. In fig. 9, which is drawn on a larger scale, there are two dilatations on the narrow part of the tube, while in fig. 11 the narrow part is long and convoluted, and extends forward to the 2nd muscle band. In fig. 10 the testis reaches the 2nd muscle band without any diminution in its calibre, and then, narrowing slightly, forms a loop extending almost to the 1st band, after which it curves back towards the 2nd, and ends in a narrow filament. The two remaining cases figured are the most remarkable of all. In fig. 8 the tube narrows rapidly opposite the 3rd muscle band, and from this point forwards almost to the 1st it remains very narrow, but with two large ovate dilatations and several smaller ones upon its course. Fig. 7 shows a case where the wider tube extends to the 2nd band and then suddenly narrows, but the fine tubule, in place of running forwards, turns posteriorly, and eventually reaches the 4th muscle band after passing through several irregular dilatations. Throughout, this male system was filled with minute granular cells (Pl. XX. fig. 12), but no distinct spermatozoa could be made out.

The most remarkable feature of this "Triton" collection of Doliolidæ is, that such vast numbers should prove to be entirely one generation of the same species, and all, with a very few exceptions, of much the same size. Questions naturally arise such as, Where have they come from? Where are the asexual forms from which they have been produced? and Why are such quantities of that species found in that locality at that time? We are not yet in a position to answer any of these questions fully. Mr MURRAY tells me that when captured, they were all drifting from the south-west to the north-east. This would carry them from the "warm area" across the "Wyville-Thomson" ridge into the "cold area," but what part of the Atlantic they came from, or how far north they are carried, is not known. Mr MURRAY states that "they were abundant during the whole time of the cruise, except when we touched upon the Faroe bank water." As far as I can judge from the numbers of specimens in the tubes collected on the different days, the configuration of the bottom and the division of the region explored into "warm" and "cold" areas has no effect whatever upon the abundance of the Doliolidæ. There are large quantities of specimens in the collection from the 3rd to the 5th August, halfway between Rona Island and the south-east end of the ridge; on the 29th August, over the centre of the ridge; on the 28th and 31st August, in the "warm area;" and on 20th to 23rd August, in the "cold area." The region from which the smallest numbers have been brought back are those explored on the 7th to the 9th August at the north-west extremity of the ridge.

Mr MURRAY has kindly supplied me with the following extracts from his

journal, which bear upon the abundance of the Doliolidæ at different times, and relatively to other surface forms :—

"*August* 5, 1882.—Doliolums were quite as abundant to-day as yesterday; they appeared to be chiefly about 10 fathoms beneath the surface. Diatoms in the stomach as usual. The immense mass of these in this portion of the sea at this time is very astonishing.

"The last year (1880), in the "Knight Errant," the most characteristic thing in the surface gatherings was the enormous multitude of Acanthometræ, and now these are almost absent.

"*August* 7.—There was quite a change this morning in reference to the general character of the tow-net gatherings. The Doliolums had quite disappeared, and Acanthometræ were now very abundant, and the most characteristic animals.

"In the afternoon, after we had moved south from the Faroe Bank, we got again the same surface animals as yesterday and the day before, viz., vast numbers of Doliolums, some Medusæ, larvæ of Medusæ or other Cœlenterates and Copepods.

"This is a somewhat remarkable change, and would perhaps indicate a current of water from a different source than the more northern water of this morning.

"*August* 18.—The Doliolums also were observed to be phosphorescent, emitting electric-like discharges which were divided like forked-lightning, and appeared to me to follow the direction of the nervous cords or filaments . . . . Doliolums and Actiniæ were again abundant throughout the day, sometimes in enormous abundance.

"*August* 24.—There are no Doliolums, and only a few Arachnactis in the nets this morning, from about 30 or 40 fathoms. . . . . Doliolums were got in some hauls at a depth of 10 fathoms during the day.

"*August* 29.—There were a large number of Doliolums on the surface during the day, indeed they masked all the other things in most of the hauls. In general, the Doliolums were most abundant about 5 or 6 fathoms beneath the surface.

"*August* 30.—During the day, in the tow-nets at and near the surface, Doliolums and Arachnactis were most abundant, filling the nets each time.

"It is remarkable that in the tow-nets, at the weights, there were not over one or two Doliolums, but many Copepods, apparently Arctic forms, &c.

"In summary, Doliolums most abundant, masking all the other things for weeks. At times the Doliolums appeared to be in vast banks, where they were very numerous; between these banks there were always a few ragglers. J. M."

Family II.—Salpidæ.

During the "Triton" expedition only two specimens of *Salpa* were obtained, but curiously enough these show the two conditions—solitary and aggregated—of the same species, *Salpa runcinata*. In August 1880, during the cruise of the "Knight Errant" in the same neighbourhood, some large specimens of *Salpa zonaria* were the only Tunicata captured.

Salpa runcinata, Chamisso.

1. Solitary form. One specimen, measuring 2·2 cm. in length, was obtained on the surface on the 18th August 1882.

2. Aggregated form. A single member of a chain was captured in the tow-net at a depth of 12 fathoms, 4th–5th August 1882.

This is the *Salpa fusiformis* of Cuvier, and has the body prolonged both anteriorly and posteriorly beyond the branchial and atrial apertures into long tapering appendages. The body proper measures 1·5 cm. in length and 1 cm. in breadth, while the anterior appendage extends beyond the branchial aperture for 1·4 cm., and the posterior appendage beyond the atrial aperture for 1·7 cm.

Salpa runcinata is a well known Scandinavian form, and has been obtained in British seas before now. Early in the present century, Dr John Macculloch described (*Western Isles*,* vol. ii. p. 187) and figured, under the name of *Salpa moniliformis*, a form which may have been the aggregate condition of *S. runcinata*. He found the chains occurring in abundance in autumn in the harbours of Canna and Campbellton. In the spring of 1821 Dr Fleming found many chains a foot and more in length upon the Caithness coast; and about thirty years later Professor Edward Forbes identified with *Salpa runcinata*, both solitary and aggregated, some specimens captured by Lieutenant Thomas, R.N., in the Orkney Seas. In 1868 Professor M'Intosh† came upon vast quantities of both the solitary and the chain form of *Salpa runcinata* upon the east shores of North Uist, in company with both forms of *Salpa spinosa*, Otto, a species which Forbes had predicted would probably be found in the Hebrides.

Salpa zonaria, Chamisso.

Ten specimens of this form were obtained in the tow-net, at a depth of 20 fathoms, on 10th August 1880, during the cruise of the "KnightErrant." The specimens are well preserved, and are all about 4 cm. in length.

* See Forbes and Hanley, *History of the British Mollusca*, vol. i. p. 50, 1853.

† See *Jour. Linn. Soc.*, Zool., vol. ix. p. 41.

Postscript.

Since the above was written, I have received from Mr Murray another "Triton" specimen. This necessitates the following addition to my report which should be inserted between "Ascidiacea" and "Family Cynthiidæ," near the top of page 95 :—

Family Molgulidæ.

Eugyra glutinans, Möller.

A single specimen of this widely distributed species was obtained in the second haul of the trawl on the 22nd August 1882, at Station 8 (in the "cold area," near the S.E. end of the "Wyville-Thomson" ridge), from a depth of 640 fathoms. This is a greater depth than any from which Molgulidæ were obtained during the "Challenger" Expedition.

The incrusting sand is very fine, and the bare area around the apertures is conspicuous. In the branchial sac there are usually about eight coils in the spiral forming each infundibulum. The specimen measures 9 mm. in breadth by 6·5 mm. in length.

EXPLANATION OF THE PLATES.

The objectives employed while drawing the figures were as follows :—

Swift, 1 inch	—magnifies about	45	diameters.
„ $\frac{1}{4}$ „	„	225	„
„ $\frac{1}{6}$ „	„	300	„
Hartnach, No. 4	„	50	„
„ 5	„	180	„
„ 7	„	330	„
Zeiss $\frac{1}{12}$, oil immersion	„	950	„

The following system of lettering has been adhered to in all the figures :—

at, atrial aperture.
br, branchial aperture.
br.f, fold in branchial sac.
c, enlarged end of tubule of intestinal gland.
d, duct of intestinal gland.
d.l, dorsal lamina.
d.t, dorsal tubercle.
en, endostyle.
g, genital mass.
gl, gland at pylorus of stomach.
g.c, nerve cells in outer part of ganglion.
h, heart.

h.m, horizontal membrane of branchial sac.
i, intestine.
i.l, internal longitudinal bar of branchial sac.
l, lobe at branchial aperture.
l.v, fine longitudinal vessel of branchial sac.
m^1 to m^8, the muscle bands in *Doliolum*.
mb, membrane.
m.b, muscular bundle.
mh, mesh of branchial sac.
n, *n'*, nerves.
n.a, aperture of duct from neural gland.
n.d, duct from neural gland.
n.g, nerve ganglion.
œ, œsophagus.
œ.a, œsophageal aperture.
ov, ovary.
p, papilla; *p'*, smaller intermediate papilla.
p.p, peripharyngeal band.
sg, stigmata.
st, stomach.
t, testis; *t'*, anterior prolongation of testis.
tn, *tn'*, *tn''*, tentacles of 1st, 2nd, and 3rd order.
tr, transverse vessel; *tr'*, *tr''*, smaller transverse vessels.
v.d, vas deferens.
z, prebranchial zone.

PLATE XVI.

Ascidia tritonis, n. sp.

Fig. 1.—*Ascidia tritonis*, seen from the right side. Natural size.
Fig. 2.—A small portion of the surface of the test. Slightly magnified.
Fig. 3.—Another specimen, after the removal of the test, seen from the left side. Natural size.
Fig. 4.—Part of the branchial sac, from the inside. Objective, Swift, 1 inch.
Fig. 5.—Small portion of dorsal lamina, showing free edge. Objective, Swift, 1 inch.
Fig. 6.—Dorsal part of anterior end of branchial sac, showing tentacles, dorsal tubercle, peripharyngeal bands, &c. Objective, Swift, 1 inch.

PLATE XVII.

Figs. 1 and 2, *Ciona intestinalis*, Linn. Figs. 3 and 4, *Ascidia virginea*, O. F. Müller. Figs. 5 and 6, *Polycarpa pomaria*, Sav.

Fig. 1.—A small portion of the branchial sac of *Ciona intestinalis*, Linn., seen from the inside; papillæ not represented. Objective, Swift, 1 inch.
Fig. 2.—Another small portion of the branchial sac of *Ciona intestinalis*, from the inside. Objective, Swift, 1 inch.
Fig. 3.—*Ascidia virginea*, O. F. Müller, var. *pedunculata*, from the left side. Natural size.

Fig. 4.—Dorsal part of anterior end of branchial sac of *Ascidia virginea* var. *pedunculata*, showing tentacles, dorsal tubercle, &c. Objective Swift, 1 inch.

Fig. 5.—*Polycarpa pomaria*, Savigny, seen from the left side. Natural size.

Fig. 6.—Part of the branchial sac of *Polycarpa pomaria*, seen from the inside, and showing two folds and two interspaces. Objective, Swift, 1 inch.

Plate XVIII.

Doliolum denticulatum, Quoy and Gaimard.

Fig. 1.—*Doliolum denticulatum* from the right side. Natural size.

Fig. 2.—A specimen preserved in chromic acid and absolute alcohol, from the left side. Natural size.

Fig. 3.—The same specimen seen from the ventral surface.

Fig. 4.—A young individual (2 mm. in length) seen from the right side. Objective, Hart. 4.

Fig. 5.—Part of a muscle band from the mantle of a specimen preserved in picric acid. Objective, Hart. 5.

Fig. 6.—Another muscle band from the same specimen. Objective, Hart. 5.

Fig. 7.—Anterior half of endostyle, seen from the interior of the branchial sac, from specimen stained in picro-carmine. Objective, Hart. 4.

Fig. 8.—Nerve ganglion, dorsal part of peripharyngeal band, &c., seen from interior of branchial sac. Objective, Hart. 4.

Fig. 9.—Broad barrel-like form of *Doliolum denticulatum*, from left side. Natural size.

Fig. 10.—Two specimens of the narrow elongated form. Natural size.

Fig. 11.—Right side of branchial sac, &c., from interior. Reduced from Objective, Hart. 4.

Fig. 12.—Nerve ganglion, neural duct, peripharyngeal band, &c. Objective, Hart. 5.

Fig. 13.—Small part of peripharyngeal band, from specimen stained in osmic acid. Objective, Hart. 7.

Plate XIX.

Doliolum denticulatum, Quoy and Gaimard.

Fig. 1.—Nerve ganglion and dorsal part of peripharyngeal band, from a specimen preserved in chromic acid and absolute alcohol, and stained in picro-carmine. Objective, Hart. 4.

Fig. 2.—The ends of some of the stigmata, from a specimen preserved in picric acid. Objective, Swift, $\frac{1}{4}$ inch.

Fig. 3.—Some of the ciliated cells bounding the stigmata, stained in picrocarmine. Objective, Hart. 7.

Fig. 4.—Some of the ciliated cells bounding the stigmata, stained with osmic acid. Objective, Zeiss, $\frac{1}{12}$, oil immersion.

Fig. 5.—Some of the cells from the surface of the peripharyngeal band of a specimen preserved in chromic acid, and stained in picro-carmine. Objective, Zeiss, $\frac{1}{12}$, oil immersion.

Fig. 6.—Part of the prebranchial zone in a specimen preserved in osmic acid and absolute alcohol. Objective, Hart. 7.

Fig. 7.—Part of the prebranchial zone enclosed by the coiled dorsal ends of the peripharyngeal band, from a specimen preserved in chromic acid and absolute alcohol, and stained in picro-carmine. Objective, Zeiss, $\frac{1}{12}$, oil immersion.

Fig. 8.—The anterior half of the nerve ganglion, showing the origin of the neural duct, from specimen stained in osmic acid. Objective, Zeiss, $\frac{1}{12}$, oil immersion.

Fig. 9.—Anterior end of the duct from the neural gland, showing its ciliated expansion and terminal aperture, from specimen preserved in osmic acid and absolute alcohol. Objective, Zeiss, $\frac{1}{12}$, oil immersion.

Fig. 10.—Posterior end of endostyle, œsophageal aperture, and the neighbouring part of the branchial sac, seen from the interior, from a specimen preserved in chromic acid and absolute alcohol, and stained in picro-carmine. Objective, Hart. 4.

Fig. 11.—Part of the heart, from specimen shown in fig. 10. Objective, Hart. 7.

Fig. 12.—Part of the ganglion, showing the origin of one of the nerves, from a specimen preserved in picric acid and absolute alcohol, and stained in picro-carmine. Objective, Zeiss, $\frac{1}{12}$, oil immersion.

Fig. 13.—A group of nerve cells from the ganglion shown in figure 12. Enlarged from Zeiss, Objective $\frac{1}{12}$, oil immersion, ocular 4.

PLATE XX.

Doliolum denticulatum, Quoy and Gaimard.

Fig. 1.—Œsophagus, stomach, intestine, digestive glands, reproductive organs, &c., of an individual preserved in alcohol, and stained in picro-carmine. Reduced from Objective, Swift, 1 inch.

Fig. 2.—Part of the duct (*d*) crossing from intestine to stomach in last figure. Objective, Zeiss, $\frac{1}{12}$, oil immersion.

Fig. 3.—Part of the digestive gland forming a network of tubules over the intestine, from same specimen as fig. 1. Objective, Swift, $\frac{1}{6}$ inch.

Fig. 4.—Part of the wall of the intestine, surface view. Objective, Hart. 5.

Fig. 5.—Part of the organ (*gl*) seen ramifying over the stomach and first portion of the intestine in fig. 1, from specimen stained in picro-carmine. Objective, Zeiss, $\frac{1}{12}$, oil immersion.

Fig. 6.—The reproductive system dissected out. Reduced from Objective, Swift, 1 inch.

Fig. 7.—The same in another specimen, showing a curious anterior termination. Reduced from Objective, Swift, 1 inch.

Fig. 8.—Anterior extremity of the testis of another individual, stained in picro-carmine. Objective, Swift, 1 inch.

Fig. 9.—Anterior extremity of the testis in another specimen, preserved in solution of osmic acid. Objective, Hart. 5.

Fig. 10.—Anterior extremity of the testis in another specimen, stained in picro-carmine. Objective, Swift, 1 inch.

Fig. 11.—Anterior extremity of the testis in another specimen. Objective, Hart. 5.

Fig. 12.—Small part of the edge of the testis near the posterior end. Objective, Hart. 7.

Fig. 13.—Opening of vas deferens close to ovary. Objective, Hart. 4.

Fig. 14.—Aperture of vas deferens. Objective, Hart. 7.

Fig. 3.

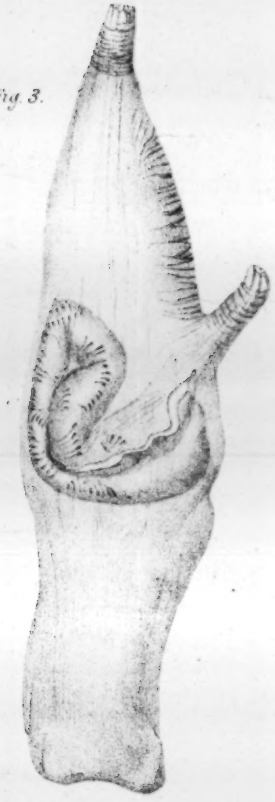


Fig. 2.



Fig. 1.

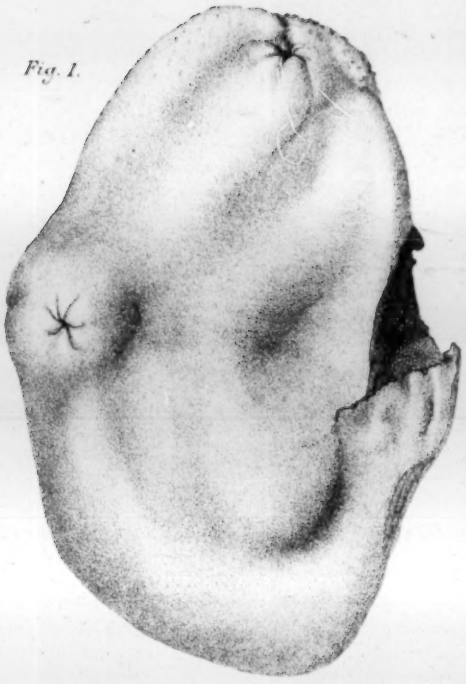


Fig. 5.



Fig. 6.

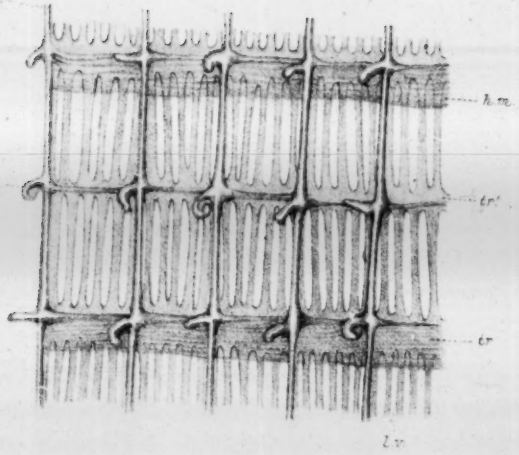


Fig. 4.



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P. Huth, Lith.ʳ Edin.ᵍ

ASCIDIA TRITONIS, n. sp.

Fig. 1.

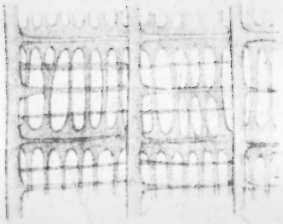


Fig. 2.

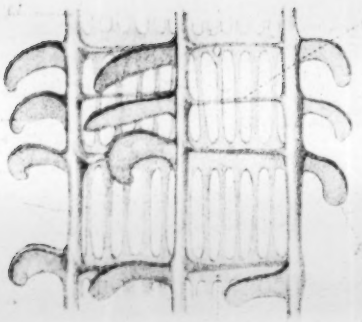


Fig. 3.



Fig. 4.

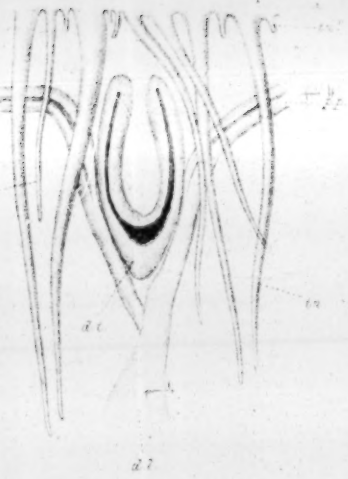


Fig. 6.

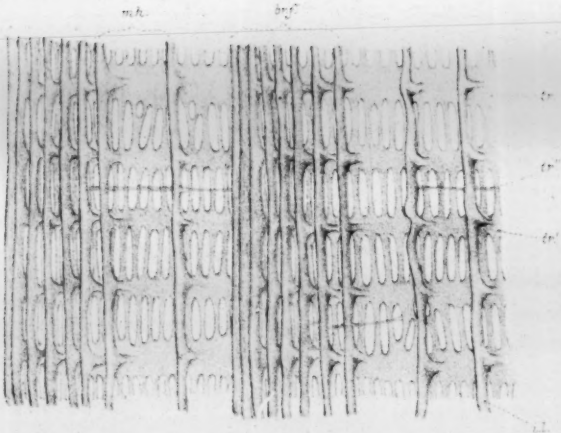
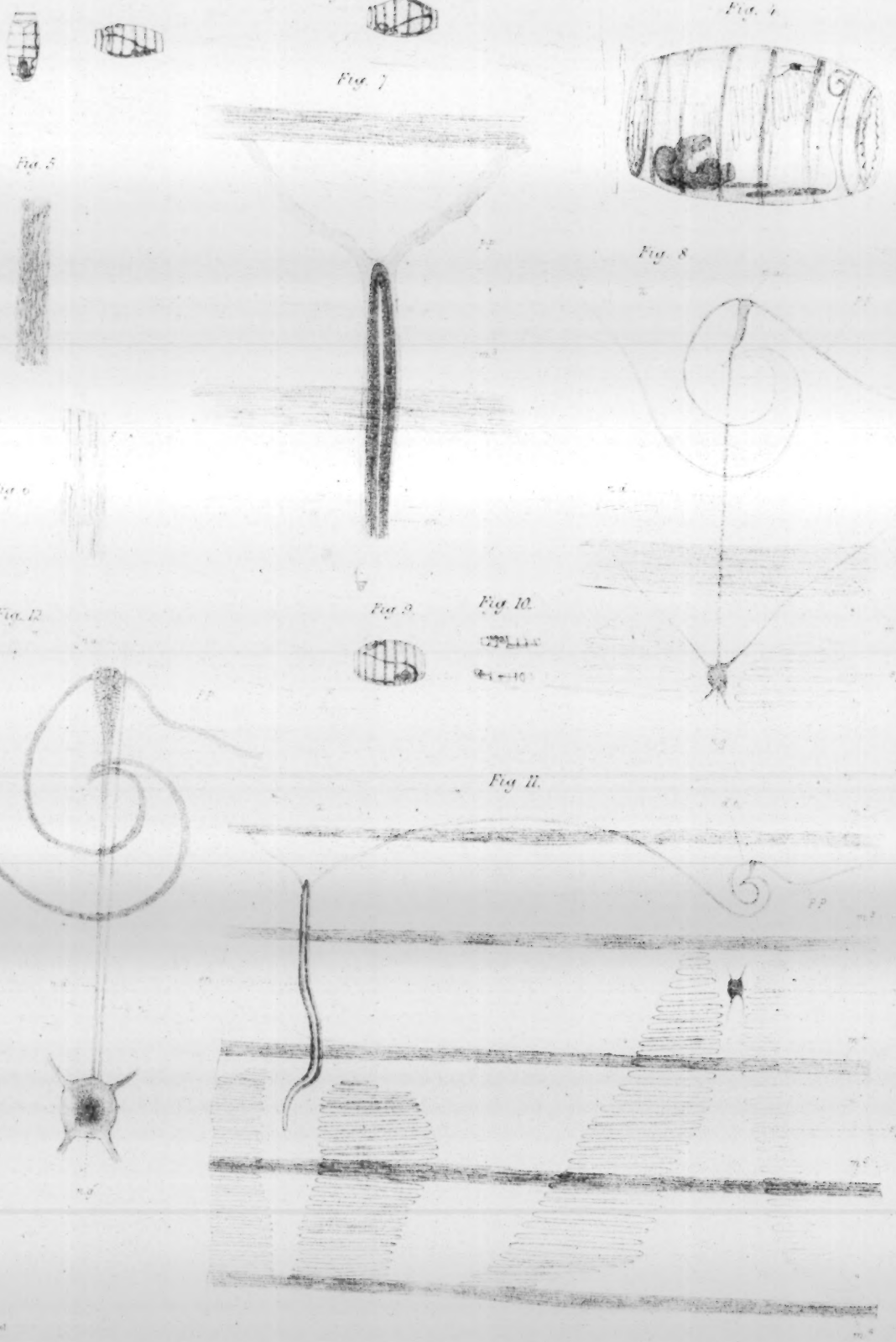


Fig. 5.



W. A. Herdman, del. P. Huth, Lith.r to R. S. Edin.r

FIGS 1 & 2 CIONA INTESTINALIS, Linn. FIGS 3 & 4 ASCIDIA VIRGINEA var. PEDUNCULATA.
FIGS 5 & 6 POLYCARPA POMARIA, Sav.



DOLIOLUM DENTICULATUM, Q. & G.

Fig. 1.



Fig. 2.



Fig. 3.

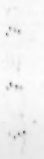


Fig. 4.

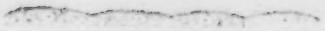


Fig. 5.



Fig. 10.

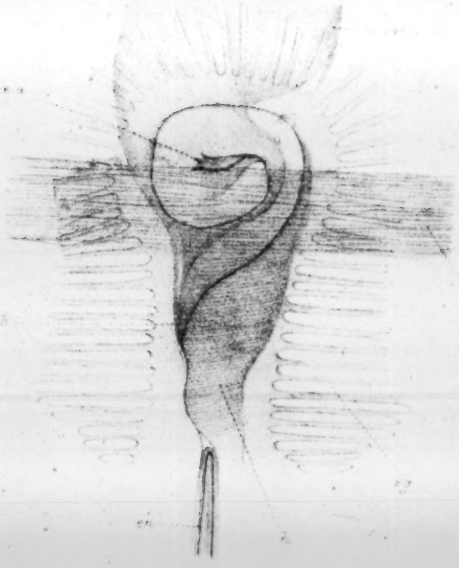


Fig. 9.



Fig. 6.



Fig. 7.

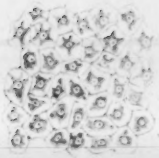


Fig. 11.



Fig. 8.

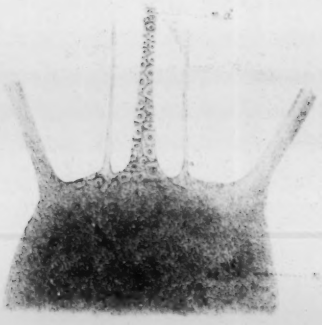


Fig. 12.

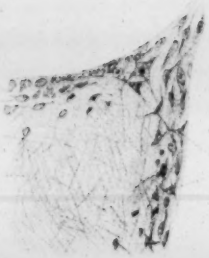
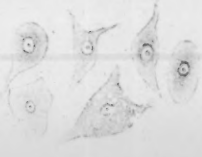


Fig. 13.



W.A.Herdman del.

DOLIOLUM DENTICULATUM, Q. & G.

Fig. 1.

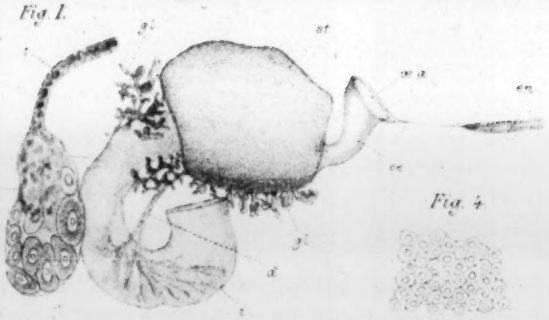


Fig. 2.



Fig. 3.



Fig. 4.

Fig. 8.



Fig. 5.



Fig. 14.

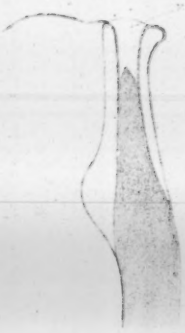


Fig. 7.



Fig. 6.

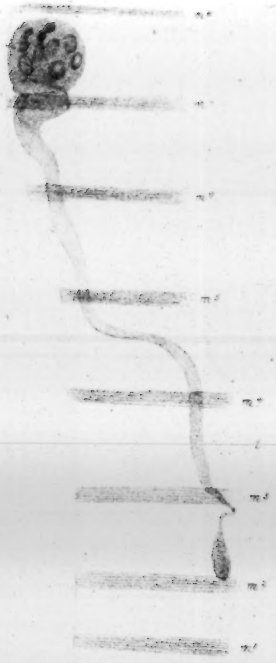


Fig. 12.



Fig. 9.



Fig. 10.



Fig. 13.



Fig. 11.



W.A. Forsman, del.

DOLIOLUM DENTICULATUM, Q. & G.

VIII.—*Report on the Pennatulida dredged by H.M.S. "Triton."*

By A. Milnes Marshall, M.D., D.Sc., M.A., Fellow of St John's College, Cambridge, Beyer Professor of Zoology in Owens College. (Plates XXI. to XXV.)

(Read 16th July 1883.)

Introduction.

The Pennatulida obtained by H.M.S. "Triton," and placed in my hands for description, are of six genera only, each genus being represented by a single species. The interest of the collection is, however, far from commensurate with its size, for of the six species two are altogether new to science, a third has hitherto been met with only off the Norwegian coast, while concerning the remainder, which are well known species, the "Triton" specimens have furnished important additions to our knowledge, either of their anatomy or distribution.

In arranging the species I have followed the system of classification proposed by Kölliker in his "Report on the Pennatulida dredged by H.M.S. 'Challenger.'"* This scheme, though representing the latest results of our greatest authority on the group, cannot be considered altogether satisfactory, inasmuch as but very little attempt is made to express the mutual relations of the several groups, and highly specialised forms are mixed up with more primitive ones in a very confusing manner. I have, however, thought it better to adopt it here rather than attempt to frame a new scheme on inadequate material.

The following outline of Kölliker's classification shows the position occupied by the genera with which we are concerned :—

Order PENNATULIDA.

Section I. Pennatuleæ: polyps fused together to form leaves.

Sub-section 1. *Penniformes:* leaves well developed.

Family 1. Pteroeididæ.

Family 2. Pennatulidæ.

Genus *Pennatula.*

Sub-section 2. *Virgularieæ:* leaves small.

Family 1. Virgularidæ.

Genus *Virgularia.*

Family 2. Stylatulidæ.

Genus *Dübenia.*

* *Zool. Chall. Exp.*, part ii. pp. 33–35, 1880.

Section II. SPICATÆ: no leaves; polyps sessile.

Sub-section 1. *Funiculineæ:* polyps arranged in distinct rows.

Family 1. Funiculinidæ.

Genus *Funiculina.*

Family 2. Stachyptilidæ.

Family 3. Anthoptilidæ.

Sub-section 2. *Junciformes:* polyps in single series or in indistinct rows.

Family 1. Kophobelemnonidæ.

Genus *Kophobelemnon.*

Family 2. Umbellulidæ.

Genus *Umbellula.*

Family 3. Protocaulidæ.

Family 4. Protoptilidæ.

Section III. RENILLEÆ: rachis expanded, in form of a leaf.

Section IV. VERETILLEÆ: polyps arranged on rachis in radiate manner.

The following table shows the localities at which the specimens were obtained, the number taken at each, and the instrument employed in each case. The specimens taken at Stations 6 and 7 do not belong to the "Triton" collection, but were dredged by the "Knight Errant" in 1880:—

Station.	Locality.	Depth in Fathoms.	Date.	Name.	Number.	How Caught.
6	59° 37′ N., 7° 19′ W.	530	Aug. 11, 1880	Kophobelemnon	1	
7	do. do.	530	Aug. 12, 1880	Pennatula	1	
8	60° 18′ N., 6° 15′ W.	640	Aug. 22, 1882	Kophobelemnon	2	
10	59° 40′ N., 7° 21′ W.	516	Aug. 24, 1882	„	3	Trawl
				„	2	Dredge
11	59°29′ 30″N., 7°13′W.	555	Aug. 28, 1882	Pennatula	18	Trawl
				„	1	Dredge
				Virgularia	2	Trawl
				„	1 fragment	Dredge
				Dübenia	1	Trawl
				Kophobelemnon	13	Trawl
				„	11 & 6 heads	Dredge
				Umbellula	1	Trawl
	Loch Linnhe, Off Castle Walker,	35–37	?	Funiculina	10 fragments	
	Off Butt of Lewis,	40	Aug. 25, 1882	Pennatula	4	Trawl

Concerning the mode of capture, it will be seen from the above table that the trawl was distinctly more successful than the dredge; and the difference between the two is greater than appears from a mere comparison of the number of specimens taken, for the proportion of imperfect and mutilated specimens brought up by the dredge far exceeds that yielded by the trawl, the mutilation being in many cases clearly caused by the dredge itself.

For such forms as Pennatulida the dredge is indeed a very unsuitable instrument of capture; a point that deserves a greater amount of practical attention than it appears yet to have received.* It is certainly worthy of note that the three most interesting forms collected by the "Triton" were all brought up by the trawl.

Concerning the nomenclature adopted, I have retained the terms *polyp* and *zooid* for the two kinds of individuals, sexual and asexual, of which a Pennatulid colony normally consists, since these names are in general use. Strictly speaking, the names are objectionable, for the term *zooid* is commonly and conveniently employed in zoology to indicate any member of a colony that is produced asexually, and in this sense both kinds of individuals of the Pennatulid colony are *zooids*.

For the tubular cavity into which the mouth leads, and which is commonly spoken of as the stomach, I have adopted the term *stomodæum*. This cavity is in no sense of the word entitled to the name of stomach, inasmuch as digestion is effected, not in it, but in the body cavity into which it opens below. Kölliker has proposed to call it œsophagus,† but the term *stomodæum* seems preferable, as indicating at once its origin by involution of the outer layer of the body or ectoderm.

Description of the Specimens.

Order PENNATULIDA.

Section I. Pennatuleæ.

Sub-section 1. *Penniformes*.

Family 2. Pennatulidæ.

Pennatula, L.

Pennatula phosphorea, L. (Pl. XXI. figs. 4–7, and Pl. XXII. figs. 8–16.)

This species was obtained by the "Triton" at two localities, off the Butt of Lewis in 40 fathoms water, and at Station 11 at a depth of 555 fathoms. The collection also includes a single specimen obtained by the "Knight Errant" in 1880.

* Cf. *Nature*. A new dredging implement, vol. xxvii. p. 11.

† Kölliker, *Anatomisch-systematische Beschreibung der Alcyonarien*, p. 416, 1872.

Of this very variable species KÖLLIKER distinguishes three well-marked varieties, characterised as follows:*—

1. Var. *angustifolia*: Leaves long and narrow; polyp heads few and wide apart.

2. Var. *lancifolia*: Leaves lancet-shaped; polyp heads numerous, and close together. Of this form, which should probably be considered the typical *P. phosphorea* rather than a distinct variety, KÖLLIKER further distinguishes four sub-varieties.

3. Var. *aculeata*: Leaves slender, and placed close together; on the ventral surface of the rachis are four to six rows of long spines, connected with the zooids.

Of the "Triton" specimens those obtained off the Butt of Lewis belong to the second variety *lancifolia*; while the more numerous specimens from the deeper water of Station 11 are typical examples of the variety *aculeata*. The two forms are so distinct that it will be well to describe them separately.

P. phosphorea var. *lancifolia*, Köll.

All four specimens are small, and of somewhat stunted appearance, the leaves being twisted in an irregular manner, so that sometimes the dorsal and sometimes the ventral border of the leaf is turned upwards. The four specimens, though of nearly the same absolute size and all obtained at one haul, differ a good deal among themselves as to the shape of the leaves and the breadth of their attachment to the rachis, and also as to the extent of separation between the component polyps of a leaf.

The zooids, which are uniform in size, cover the whole ventral surface of the rachis, except the mid-ventral groove, and extending upwards between the leaves, become continuous with small groups of three or four zooids each situated on the dorso-lateral angles of the rachis between the leaves.

In all four specimens the stalk, with the exception of the terminal dilatation, which is yellowish, is of a dark red colour, due, as in the rachis and leaves, to the calcareous spicules imbedded in it. In one specimen the colour is a deep purple of exceptional intensity.

The measurements of the four specimens in millimètres are as follows:—

	A.	B.	C.	D.
Length of colony, . .	60 mm.	56 mm.	58 mm.	58 mm.
„ rachis, . .	31·5	27	31	30
„ stalk, . .	28·5	29	27	28
„ leaves, . .	13	13	12	11·5
Greatest width of leaves, .	2	2·5	3	3
No. of leaves on each side, .	20	21	22	20
„ polyps per leaf, .	10	9	9	10

* KÖLLIKER, *Anatomisch-systematische Beschreibung der Alcyonarien*, pp. 130–134.

From these figures it will be seen that specimens A and B approach very closely KÖLLIKER's variety *angustifolia.*

P. phosphorea var. *aculeata,* Köll. (Pl. XXI. figs. 4–7, and Pl. XXII. figs. 8–16.)

This very well-marked variety, which does not appear to have been hitherto recorded from British seas, is characterised by the long and slender shape of the leaves (Pl. XXI. figs. 4 and 5), the small number of their component polyps, their distance apart, and the extent to which they are separate from one another; and above all, by the fact that a number of the zooids of the ventral surface (figs. 4 and 5, *f*) are very exceptionally developed—assuming the form of conical spines, which project from the rachis for a distance in some specimens of 3·5 mm., or even more.

This variety was first described in 1858 by KOREN and DANIELSSEN,* who found it at a single locality near Christiansund, where it occurred rather abundantly on clay bottom at the depth of 80 to 100 fathoms. Since then it has been taken by SARS at Christiansund at a depth of 30 to 70 fathoms, and in the Throndhjemsfjord in 100 fathoms water; by CARPENTER and WYVILLE THOMSON, during the "Porcupine" expedition in the Atlantic Ocean, 48° 26′ N., 9° 44′ W., at a depth of 358 fathoms; and by WHITEAVES in the Gulf of St Lawrence, at a depth of 160 to 200 fathoms.

Of the "Triton" specimens of *P. phosphorea,* all those, 19 in number, obtained at Station 11, depth 555 fathoms, belong to this variety, as also does the single specimen from the "Knight Errant" collection dredged at Station 7, in 530 fathoms water. As the variety is a very interesting one, and has not yet been satisfactorily described, I have taken the opportunity afforded by the large number of specimens available to investigate in some detail the more important structural details, directing my attention more particularly to the large ventral zooids.

The following table gives the measurements of the single specimen from the "Knight Errant" and of two of the "Triton" specimens. All the latter are of small size, the specimen B being one of the largest.

	A. "Knight Errant" Collection.	B. "Triton" Collection.	C. "Triton" Collection.
Length of colony,	70 mm.	62 mm.	48 mm.
„ rachis,	31	28·5	24
„ stalk,	39	33·5	24
„ leaves (longest),	12	13	10
Greatest width of leaves,	3	1·5	1·5
Number of pairs of leaves,	19	14	10
Number of polyps per leaf,	9	6	7
Length of largest zooids,	3	3·5	3

* KOREN and DANIELSSEN, *Forhandlinger i. Videnskabsselskabet i. Christiania,* p. 25, 1858; also *Fauna Littoralis Norvegiæ,* part iii. pp. 86–88, and pl. ii. figs. 8 and 9, Bergen, 1877.

Koren and Danielssen, Whiteaves and Verrill, maintain the specific distinctness of this form from *P. phosphorea*. The measurements of the different specimens I have been able to examine show so great variability in the essential characters of the form, such as the length of the large zooids, width of leaves, &c., that I can have no hesitation in agreeing with Kölliker* in regarding it as merely a variety, though a very well-marked one. I cannot, however, accept Richiardi's† conclusion that it is not even a variety, "ma uno stato puramente accidentale di certi exemplari."

The general appearance of the form is shown in Pl. XXI. fig. 4, representing an entire specimen seen from the right side and twice the natural size. Fig. 5 is a transverse section through the rachis about the middle of its length, with one of the attached leaves and the base of the corresponding leaf of the opposite side. For the sake of comparison, I have given in fig. 6 a similar view of a normal specimen of *P. phosphorea* obtained from Oban.

If these two figures be compared together, it will be seen that the points in which the variety *aculeata* (fig. 5) differs from the typical *P. phosphorea* (fig. 6) are the following :—The leaf is longer and much narrower; the polyps are fewer in number, are placed further apart, and are independent of one another for a greater portion of their length. The walls of the rachis are much thicker, a condition associated with the presence of larger and more numerous spicules; the axial calcareous stem is thicker, and the main longitudinal canals of the rachis much smaller than in the typical form. Concerning the zooids, it will be seen that a very large one (fig. 6, *f*) arises from the rachis immediately below each leaf, with the ventral border of which it is fused for about a third of its length. Nearer the mid-ventral line of the rachis there is on each side a second row of large zooids, usually slightly smaller than those of the outer row, but sometimes equalling them in size; and within these again other zooids occur intermediate in size between the large ones and the normal small ones. The largest zooids, those attached to the ventral borders of the leaves, have an average length of rather over 3 mm. in the "Triton" specimens; in exceptional cases they reach 4 mm.

Between the large zooids are numerous small ones of the normal size and character, which extend up the sides of the rachis between the bases of the leaves.

That the connection of the large ventral zooids with the leaves is of a purely secondary nature is clearly seen by tracing their gradual development in passing upwards from the lower end of the rachis. At their first appearance they are small, identical in all respects with the normal zooids, and quite inde-

* Kölliker, *Op. cit.*, pp. 134 and 366.

† Richiardi, *Monografia della famiglia dei Pennatularii*, p. 24.

pendent of the leaves, with which they become connate only after they have attained a considerable size.

The structure of the large zooids, which does not appear to have been examined with any care hitherto, is shown in the series of figures on Plate XXII. Of these fig. 8 represents a median longitudinal section through the whole length of one of the zooids, and through the part of the rachis from which it springs; while figs. 10 to 16 are transverse sections through a zooid at different parts of its length, fig. 10 being near to the apex and fig. 16 passing through the base of attachment of the zooid.

The general anatomy of the large zooid is well shown in fig. 8, from which it will be seen that while agreeing in essential structure with the smaller and more typical zooids, it yet presents some points of special interest.

The zooid is conical in shape, arising by a broad base from the rachis and tapering upwards rather sharply, ending in a pointed apex. As shown in figs. 4 and 8 the zooid does not project horizontally outwards, but obliquely upwards, so that we can distinguish between an inner or axial surface, directed toward the rachis, and an outer or abaxial surface facing outwards.

On the inner or axial surface, and nearer the base than the apex of the zooid, is the mouth (fig. 8, *n*). This leads into the stomodæum *s*, which is lined by columnar ciliated ectoderm cells, the cilia clothing the outer or abaxial wall being of very great length, and forming with the surface of the stomodæum from which they arise the structure which Mr Hickson has recently proposed to speak of as the siphonoglyphe.*

The stomodæum opens below into the general body cavity *h*, which is lined by endoderm, and is in communication with the cavities of the adjacent zooids and with the main lateral canals of the rachis, and so indirectly with the polyps. The stomodæum is attached to the body wall by the usual eight septa, which are well shown in the transverse section (fig. 15). Below the stomodæum the two septa of the inner or axial surface, bounding the axial interseptal cavity, remain of considerable width, and bear at their free edges the two mesenterial filaments (figs. 8 and 16, *p*), which are very long and much convoluted, and extend down to the bottom of the zooid cavity.

The other six septa become reduced immediately below the stomodæum to very narrow ridges (fig. 16, *m*), which disappear altogether a short way lower down.

The body wall of the zooid consists of an outer layer of short columnar ectoderm cells, below which is the firm gelatinous mesoderm. This latter is much thicker on the outer or abaxial surface than it is on the inner or axial, and is strengthened by a great number of large calcareous spicules (figs. 8–16, *i*). These spicules are straight rods, thickest in the middle, and with rounded ends;

* Hickson, on the "Ciliated Groove (Siphonoglyphe) in the Stomodæum of the Alcyonarians," *Proc. Roy. Soc.*, 1883.

the largest attain a length of 1·6 mm., with a width of ·13 mm. In transverse section (figs. 10–16, *i*) the spicules are triangular, with rounded angles, and a shallow groove running somewhat obliquely down the middle of each face. They are exceedingly numerous along the whole length of the abaxial surface of the zooid, and are arranged with their long axes parallel, or nearly so, to that of the zooid.

The mesoderm is traversed by a system of irregularly branching nutrient canals continuous with those of the rachis. The muscular system of the body wall of the zooid seems to be completely absent.

The relations of the inter-septal chambers in the part of the zooid above the stomodæum are rather curious. Fig. 14 represents a transverse section through the mouth opening; it shows that at this point only five of the eight inter-septal chambers are present, viz., the abaxial, or as it is commonly called, ventral cavity, the two latero-ventral cavities bounding it on either side, and the two lateral cavities; the axial or dorsal and the two latero-dorsal cavities not extending above the mouth. In a section taken a little higher up, through the upper part of the mouth (fig. 13), the two lateral cavities have disappeared, and the mid-ventral and latero-ventral cavities are alone present. Tracing them further up towards the apex of the zooid, we find that all three persist for some distance, but that after a time the middle abaxial or ventral cavity, which has been from the start the smallest (*cf.* figs. 15 and 14), loses its lumen (fig. 12), and then disappears altogether, the two latero-ventral cavities alone persisting (fig. 11).

Further up still (fig. 10), one of the two latero-ventral cavities disappears and one alone is left, which can be traced nearly, or in some cases quite, up to the apex of the zooid.

The prolongations upwards of the interseptal chambers above the mouth correspond, not to the tentacular cavities of the fully formed polyps, but to the cavities of the calyx processes; and the whole of the part of the large zooid above the mouth is to be regarded as formed by a special unilateral development of the calyx, corresponding at its base to five, and along the greater part of its length to three calyx processes fused together, but with their axial cavities remaining distinct.

That the spine of the large zooid really consists of calyx processes and not of tentacles, is, I think, proved by the perfect continuity between the wall of the zooid itself and the spine; by the unbroken series of exceptionally large spicules extending along the abaxial wall of the whole length of the zooid, including the spine; and by the absolute identity between a transverse section across the upper part of the spine, and one through a calyx process of a normal polyp. This latter point is well shown in figs. 9 and 10, the former being a section of a calyx process, and the latter of the spine of one of the large zooids.

The agreement will be seen to be absolute, even as regards the actual size and arrangement of the spicules, which in both cases are far larger and more abundant on the abaxial or outer surface than on the axial or inner one. It is also worthy of note, in connection with the point in question, that in the development of the polyps the calyx processes appear earlier than the tentacles (*vide* fig. 7).

The large zooids of *P. phosphorea* var. *aculeata* agree, therefore, with the zooids of Pennatulida generally in the complete absence of tentacles, as well as in the absence of reproductive organs and the possession of but two mesenterial filaments. They are peculiar merely in their very great absolute size, and in the prolongation of the abaxial surface to form the spine.

The structure of one of the normal small zooids is shown in fig. 8, *e*. It will be noticed that here also the mouth, which in the early stages of development is terminal (as shown in the rudimentary zooid between *e* and the large zooid), becomes thrown over to the axial surface by growth forwards of the abaxial side, which forms a prominence above the mouth clearly comparable to the spine of the larger zooids. The figure shows also that the smaller zooids, like the large ones, possess the clothing of exceptionally long cilia on the abaxial surface of the stomodæum (siphonoglyphe of HICKSON).

The small zooid in question (fig. 8, *e*) is an immature one, as there is as yet no communication between the stomodæum and the body cavity of the zooid; the septa and mesenterial filaments have also not yet appeared.

PANCERI* has described and figured an interesting abnormality occurring in a specimen of *P. phosphorea*, in which four of the latero-ventral zooids, three on the left side of the rachis and one on the right, have the form and structure of fully developed polyps, inserted independently into the rachis, and attaining a length of 10 mm. and a diameter of 1 to 2 mm. In describing this curious modification, PANCERI discusses briefly the mutual relations of polyps and zooids, points out the fundamental and essential correspondence between the two, and infers that the zooids must be regarded as abortive polyps, and that such cases as the one he describes are to be viewed as examples of reversion from the abortive to the fully developed condition.

In this view PANCERI is undoubtedly right. In a colony of individuals formed by continuous gemmation, *i.e.*, by a process of budding in which the several zooids remain organically connected together to form the colony, the several component individuals must be supposed to be primitively all alike and equivalent to one another. Differences in structure and function could clearly only have arisen after the habit of forming colonies had been established for some time. Hence those colonies will be the most primitive in which there is

* PANCERI, "Intorno ad una forma non per anco notata negli zooidi delle pennatule," *Rendiconto dell'Academia delle scienze fisiche ê matematiche*, pp. 23–28, Napoli, Febbrajo, 1870.

in the adult form the smallest amount of difference between the constituent individuals; while those forms in which this differentiation reaches its greatest development will be the most highly modified forms. These principles are of great importance in framing a scheme of classification of a colonial group such as the Pennatulida, and have not received sufficient attention in the classification at present in use.

In the ordinary *P. phosphorea* the amount of differentiation is comparatively slight, and is brought about in the simplest possible manner; the asexual zooids being simply arrested at what is merely an early stage of development in the case of the polyps. This is well shown in Pl. XXI. fig. 7, representing a side view of the lower end of the rachis, and showing the early stages of development of the polyps and zooids.

The figure shows that the young polyps *d* are at first quite independent of one another, and that in their earlier stages they are absolutely identical with the zooids *e*; and that the differences arise from the zooids becoming arrested at this early stage, while the polyps advance further, increase in size, acquire calyx processes *l*, and tentacles *t*, fuse with one another at their bases, so that their further increase in length gives rise to the leaf of the adult, and acquire the full number of mesenterial filaments, and ultimately reproductive organs.

The differentiation is thus of the simplest possible character, the zooids being simply arrested or abortive polyps, whose function is apparently to maintain currents of water circulating throughout the colony, for which purpose they have retained the sole structure peculiar to them—the clothing of exceptionally strong cilia on the abaxial surface of the stomodæum. As the siphonoglyphe is present in the mature polyps of many Alcyonarians, such as Alcyonium (*vide* Hickson, *loc. cit.*), it seems certain that in the Pennatulida it is a structure that has been lost by the polyps, but retained by the zooids.

In the variety *aculeata* differentiation has advanced further; and it is a point of importance to note that the points in which the large zooids differ from the small ones cannot be considered as repetitions of any part of the process by which the polyp is developed from the zooid condition. In the young polyp all the calyx processes arise simultaneously (fig. 7), as do also all the tentacles, so that the asymmetrical development of the calyx in the large zooids must be regarded as peculiar to and acquired by them. The lateral position of the mouth in the large zooids has apparently been acquired independently of and previous to the formation of the calycular spine, inasmuch as it is an equally prominent feature in the normal small zooids (fig. 8, *e*).

Judging from their structure, the large zooids would seem to be protective in function, but as to the special circumstances which determine their development in particular forms, we are in complete ignorance. Were our knowledge confined, so far as these forms are concerned, to the "Triton" specimens, we

should be greatly tempted to suppose that as one set of specimens—the typical *P. phosphorea*—is obtained from a depth of only 40 fathoms, and the other, the variety *aculeata*, from 555 fathoms, that the structural differences between the two forms may be at any rate in part due to the different external conditions of pressure, &c.

Although, however, the variety *aculeata* does appear to occur as a rule in deeper water than the more normal form, yet this rule is not universal, for, as we have seen above,* SARS obtained specimens of *aculeata* off the Norwegian coast at depths of 30 to 70 fathoms. The determining cause therefore that leads to the production of the variety *aculeata* must be some other than mere depth, though this would appear to have some influence.

It may be noticed, finally, that the vertical range of *P. phosphorea*, which KÖLLIKER† puts at 30 to 300 fathoms, has been nearly doubled by the "Triton" dredgings, which show that the species lives in abundance, though in a rather diminutive form, as low as 555 fathoms.

Sub-section 2. *Virgularieæ*.

Family 1. Virgularidæ.

Virgularia, Lam.

Virgularia tuberculata, n. sp. (Pl. XXI. figs. 1–3.)

Specific Characters.—Polyps nearly sessile, united at bases in groups of three, the groups alternating on the two sides of the rachis. Calyx completely obliterated when the polyp is fully protruded; calyx margin marked by eight small tubercular processes placed opposite the tentacles. Reproductive organs in the immature leaves at the lower part of the rachis. Stem cylindrical. Colour of colony, yellowish-white. No calcareous spicules in any part.

Habitat.—Station 11.

Of this species three specimens were obtained, all of which are imperfect. The largest specimen (Pl. XXI. fig. 1) measures 68 mm. in length, and consists of the stalk and lower part of the rachis; its upper end is abruptly truncated, and the upper 10 mm. of the stem are denuded of the fleshy sarcosoma.

The second specimen is similar to the first, but smaller in all its dimensions; it has a total length of 36·4 mm., and consists of the stalk and lower end of rachis, the upper end of which is abruptly truncated.

The third specimen is 46 mm. long, and consists of the middle portion of the rachis of an apparently rather larger specimen than either of the other two; truncated at both ends.

* *Supra*, p. 123.

† *Zool. Chall. Exp.*, part ii. p. 38, 1880.

The stalk of the first specimen (Pl. XXI. fig. 18) is cylindrical, with an average diameter of 2·1 mm. It presents a slight terminal dilatation at its lower end, and is marked on both dorsal and ventral surfaces by shallow median longitudinal grooves. The stalk has a length of 15 mm., and is continuous above with the rachis, the transition from one to the other being marked by the first appearance of the leaves.

The lower part of the rachis is flattened dorso-ventrally, and has a transverse diameter of 2·6 mm. It is marked by upward continuations of the median dorsal and ventral grooves of the stalk.

As we pass from the region with immature leaves to the part of the rachis bearing fully developed polyps, the rachis gradually becomes reduced in width, and in the upper part, where the polyps have attained their full size, it becomes cylindrical, with a diameter in the first specimen of 0·5 mm., forming in fact a very thin fleshy investment to the stem.

The stem is cylindrical at its upper end, with a diameter of 0·4 mm.; it remains of nearly uniform size throughout the whole length of the rachis, but tapers gradually as it passes down the stalk. It is of considerable brittleness, especially in its upper part.

The polyps commence in the lower part of the rachis as small transverse ridges placed very close together, the first 6 mm. of the rachis having 20 of these ridges on each side. Passing upwards, the ridges become more prominent, wider, and situated further apart, each being divided at its free edge into three polyps.

Of the three polyps of a ridge, the dorsal one is from the start the smallest of the three, and the ventral one the largest; and these proportions are retained throughout.

As the polyps get larger, the groups move further and further apart, until the interval between successive groups on the same side of the rachis is about 3 mm., which appears to be the limiting distance.

The ridges on the lower part of the rachis are so placed that while the dorsal polyps of the ridges of the two sides are almost in contact with one another in the mid-dorsal line, the ventral polyps are separated from one another by nearly the whole width of the ventral surface of the rachis, an arrangement which persists also in the fully formed polyps (fig. 2).

The groups of polyps are from the first placed, not opposite one another, but alternately, as shown in figs. 1 and 2, the right hand group being a little in advance of the left one.

The polyps of each fully developed group are almost completely independent of one another, their bases alone being united together, so that it is hardly possible to speak of distinct leaves. The inclusion of the species in the genus *Virgularia* is fully justified, however, by the general mode of development of

the polyps, especially the simultaneous appearance of the component polyps of a group; by the position of the reproductive organs in the immature polyps, the proportions of the stem at different heights, and by the existence of such forms as *Virgularia bromleyi** in which the separation of the polyps is not carried quite so far as in *V. tuberculata*. From *V. bromleyi*, the new species is distinguished at once by the absence of calcareous spicules, and the presence of the tubercles marking the calyx margin.

Concerning the development of the polyps, it can be ascertained by examination of the immature polyps at the lower end of the rachis, that the stomodæum arises as usual as an involution of the ectoderm, appearing before the tentacles, which latter all develop simultaneously. In the early stages of development one tentacle is very commonly rather larger than the other seven, but whether this is an accidental feature or not I have been unable to determine, nor have I detected any constancy of position of the larger tentacle. In each group the ventral polyp is always the furthest developed, and the dorsal one the least so.

In the smaller of the two specimens in which the stalk is perfect, the change from the immature to the fully developed polyps is a very abrupt one; not gradual as in the larger specimen figured (Pl. XXI. fig. 1). The stalk in this smaller specimen is 8 mm. long; the first 4 mm. of the rachis bear immature leaves only, and above this point the fully formed polyps commence abruptly.

The fully expanded polyp (fig. 2) measures about 2·5 mm. in length, of which the tentacles form rather more than half; its width is about 0·2 mm. Opposite the insertion of the polyp, and for some little distance above and below it, the sarcosoma of the rachis is markedly thickened (fig. 2), giving the rachis at these places a quadrangular shape. The boundary line between the body of the polyp and the tentacles is indicated in the fully expanded polyp by a row of eight small knob-like processes placed opposite the tentacles (fig. 2). These processes are hollow, and consist of all three layers of the body wall—ectoderm, mesoderm, and endoderm; they appear to correspond to the calyx processes of other Pennatulida.

When the polyp is retracted, as in the lower specimens of fig. 2, these processes mark the line of invagination, and become much more conspicuous, appearing as knobs placed round the edge of the calyx.

In the "Triton" specimens, retraction of the polyp is never carried further than is shown in fig. 2, the fully retracted polyp being about half the length of the fully expanded one. Retraction is probably effected slowly, as the great majority of polyps have died in an almost completely expanded state.

The tentacles are rather longer than the body of the polyp; are pinnated as shown in fig. 2, and present no special features of importance.

* Kölliker, *Zool. Chall. Exp.*, part ii. p. 9, 1880.

The anatomy of the polyp, so far as I have had the chance of investigating it, agrees with that of other *Virgulariæ*. The reproductive organs, as in *Virgulariæ* generally, are contained, not in the mature polyps, but in the immature ones at the lower end of the rachis.

The large specimen (fig. 1) is a male, and a small part of the rachis removed from a point 22 mm. from the lower end of the stalk, showed the mature male organs or spermatospheres. These (fig. 3) have the typical structure of the male organs of Pennatulids. They are oval or spherical bodies, the largest of which have a diameter of 0·38 mm. Each is enclosed in a very thin capsule, the contents of which are a mass of very minute brightly refracting bodies—the heads of the spermatozoa; these are more closely packed at the periphery than in the centre, where a number of fine radiating filaments can be seen, which are probably the spermatozoa tails.

The smaller specimen, in which the lower end of the rachis is present, was also examined for reproductive organs, but none were found. The third specimen, consisting of the middle part alone of the rachis, is of course devoid of reproductive organs.

This specialisation of the reproductive organs to the immature polyps is undoubtedly a sign of considerable differentiation, and marks *Virgularia* as a less primitive genus than such a form as *Pennatula*. For while in the latter the component individuals of the colony are of two kinds only—zooids and polyps—in *Virgularia* they are of three kinds—zooids, nutrient individuals, and reproductive individuals. Whether all the immature polyps ultimately develop into mature ones is uncertain; probably not, inasmuch as all recorded specimens of *Virgularia* have immature polyps at the lower end of the rachis. The abrupt transition from the immature to the mature polyps described above as occurring in the second example of *V. tuberculata*, may perhaps indicate the existence of a sharp line of demarcation between the sexual and the nutrient individuals.

Whether zooids are present or not in *V. tuberculata*, I have been unable to determine with certainty without destroying the specimens. Certain very small knob-like projections on the rachis near the base of the polyps may perhaps prove to be zooids; if so, they are in an exceedingly rudimentary condition.

As noticed above, all three specimens of *V. tuberculata* are imperfect, and their imperfection is of some interest, inasmuch as it is very characteristic of dredged specimens of *Virgularia* generally. Of the type species, *V. mirabilis*, a perfect specimen has never yet been seen, all the specimens recorded being fractured either at one or both ends. The lower ends or stalks are occasionally found perfect, but the upper end never, the only known exception being a single specimen in the Glasgow Museum.

The cause of this mutilation has been elsewhere discussed. It has been

suggested * that the lower fracture, which usually occurs about the junction of stalk and rachis, *i.e.*, about the point of emergence from the mud of the sea bottom, is caused by the dredge at the moment of capture; while the upper fracture is almost certainly effected quite independently of the dredge, and is perhaps due to the tops being browsed on as food by other animals. The great brittleness of the calcareous stem probably accounts for the readiness with which the specimens become broken, and the fact that of the three specimens of *V. tuberculata*, the one brought up by the dredge is broken at both ends, while the two taken with the trawl have their lower ends entire, speaks strongly in favour of the correctness of the first part of the above explanation.

The measurements of the three specimens are as follows:—

	A. Upper end imperfect.	B. Upper end imperfect.	C. Both ends lost.
Total length,	68 mm.	36·4 mm.	46 mm.
Rachis,	53	28·4	46
Stalk,	15	8	...
Diameter of rachis,	0·5 to 2·6	0·4 to 2·1	0·52
„ stalk,	2·1	1·1	...
„ stem,	0·4	0·38	0·4
No. of polyps per leaf,	3	3	3
Length of polyp,	8	...	1·1
„ tentacle,	1	...	1·4
Distance of polyps apart (greatest),	3	...	3·1
Diameter of spermatospheres,	0·38	...	...

Family 2. Stylatulidæ.

Dübenia, Kor. and Dan.

Dübenia abyssicola var. *smaragdina* (Kor. and Dan.). (Pl. XXIII. figs. 17–21.)

A single fragment of this species was obtained from Station 11 at a depth of 555 fathoms. The specimen, which is imperfect at both ends, and has a total length of 61 mm., is represented from the ventral surface three times the natural size in Pl. XXIII. fig. 17; while figs. 18 and 19 represent on a larger scale portions of the rachis as seen from the lateral and dorsal surfaces respectively.

Inasmuch as the sole description that has yet appeared of this very beautiful form is the extremely short and imperfect account given by Koren and Danielssen,† I have thought it well to investigate and describe the "Triton" specimen as fully as could be done without injury to it.

The rachis (figs. 17, 18, and 19) is cylindrical, and only slightly exceeds in diameter the cylindrical stem by which it is traversed throughout its length. At the upper end of the specimen the stem projects bare for a length of about

* *Vide* Report on the Oban Pennatulida, by A. M. Marshall and W. P. Marshall, 1882, pp. 57-60.

† *Fauna littoralis Norvegiæ*, part iii. p. 26, and pl. x. figs. 7 and 8, 1877.

3 mm. above the uppermost polyps, ending in an abruptly truncated and evidently broken extremity. At the lower end the fracture appears to have occurred about the junction of stalk and rachis, but the fleshy sarcosoma has been stripped off the lowermost 8 mm., leaving this part of the stem bare, and rendering it impossible to localise exactly the seat of fracture. The stem is quite as brittle as that of *Virgularia*, so that there can be little doubt that the cause of fracture is the same in the two cases.

The entire specimen is of a pale yellowish-white colour, but has become a good deal discoloured in parts, apparently from the action of the spirit in which it was preserved.

The polyps (figs. 17, 18, and 19) are arranged in pairs along the sides of the rachis, each pair being embraced at its base by the fan-shaped plate of calcareous spicules *k*, so characteristic of the family *Stylatulidæ*. The pairs of polyps are not inserted opposite one another, nor do they strictly alternate; but those of the left side are situated a little further forward, nearer the upper end of the rachis, than the corresponding pairs of the right side.

The intervals between successive pairs of polyps on the same side of the rachis (fig. 17) gradually increase in passing upwards. At the lower end of the specimen the successive pairs are almost in contact with one another, but in passing upwards they move further and further apart, the intervals attaining a maximum a short way below the upper end of the specimen, above which point they decrease slightly, the polyps themselves also becoming smaller.

The characters and relations of the fan-shaped spicular plates are well shown in figs. 18 and 19. Each plate is triangular, with the apex directed downwards and inserted into the rachis, and with its free upper edge surrounding the base of the pair of polyps to which it belongs. The plate is formed by the fusion of a number of radiately arranged spicules, of which the more deeply placed ones are smaller and completely fused together, while some of the more superficial ones are much larger, and not so closely fused. One of these large spicules is represented in fig. 21; it is widest near its lower end, and gradually tapers upwards to a point, which (figs. 18 and 19) projects freely for a short distance above the upper edge of the plate. These large spicules may attain a length of 2·3 mm. and width of 0·15 mm. From the apex of the spicular plate a number of smaller rod-like spicules (fig. 18) are continued for a variable distance down the rachis.

The two polyps of each pair have their bases, which are covered by the spicular plate, fused together so as to form a rudimentary leaf. Above the level of the top of the spicular plate they are, however, completely free from one another. Of the two polyps, the dorsal one is always slightly smaller than the ventral one in accordance with the general rule among Pennatulida. The dorsal polyps of corresponding pairs are separated from one another by but a

slight interval (fig. 19), while the ventral polyps are separated by the whole width of the ventral surface of the rachis.

The polyps are retractile, and the extremes of contraction and expansion are represented in the two polyps of the upper pair in fig. 18. As the figure shows there is no calyx formed during retraction, and the tentacles appear to contract to a less extent than the bodies of the polyps. As in the case of *Virgularia tuberculata*, the fact that the majority of the polyps have died in an expanded or half-expanded condition may be taken as evidence that contraction is effected slowly.

Each tentacle is supported on its outer or aboral surface by a strong rib of calcareous spicules shown on a larger scale in fig. 20. These spicules are placed for the most part obliquely, running upwards and outwards; they have an average length of 0·13 mm. and diameter of 0·02 mm. They do not extend into the pinnules.

At intervals along the body walls of the polyps spicules are found similar to those of the rachis, but rather smaller and less abundant.

Concerning the reproductive organs I have no observations. According to KOREN and DANIELSSEN,* these are normally situated in the body cavities of the fully developed polyps in the genus *Dübenia;* but a large polyp from the middle of the colony, which I opened for the purpose, had no trace of reproductive organs.

The zooids are few in number, and very small and inconspicuous. They occur (fig. 19, *e*) as small rounded swellings on the dorsal surface between the pairs of polyps, and also on the sides of the rachis just above the polyps.

The genus *Dübenia* was established by KOREN and DANIELSSEN in 1874,† and was at first named *Batea*, but that name being already appropriated for a genus of Crustacea, it was changed in 1877 to *Dübenia*. It includes those members of the family *Stylatulidæ* in which the polyps, though fused at their bases, do not form distinct leaves, the fusion not extending above the calcareous fan-shaped spicular plate. The validity of the genus has been questioned by VERRILL and by RICHIARDI, but is accepted by KÖLLIKER in his Report on the "Challenger" Pennatulida, and may be considered as established.

The "Triton" specimen has all the characters of *Dübenia abyssicola* var. *smaragdina*, as defined by KOREN and DANIELSSEN.‡ This variety differs from the typical *D. abyssicola* in its more slender form, in its pale colour, and in having the polyps in groups of two instead of three or more. KOREN and DANIELSSEN express a doubt as to whether it should not be considered a distinct species rather than a mere variety, a doubt which I must share without

* *Op cit.*, p. 24.

† *Magazin for Naturvidenskaberne*, 1874.

‡ KOREN and DANIELSSEN, *Fauna littoralis Norvegiæ*, part iii. p 96, 1877.

attempting to remove, as I have had no opportunity of examining specimens of the typical *D. abyssicola*.

The variety *smaragdina* has hitherto only been recorded from the Ramsfjord close to Alvœrströmmen, two miles from Bergen, where it was found "at a depth of 100 to 120 fathoms on a clayey sand bottom," in company with the typical *D. abyssicola*, but in smaller numbers.

The measurements of the "Triton" specimen are as follows, those of two specimens described by KOREN and DANIELSSEN being given for the sake of comparison:—

	A. "Triton" specimen, imperfect at both ends.	B. Swedish specimens, entire.	C. Swedish specimens, entire.
Total length,	61 mm.	268 mm.	200 mm.
Rachis,	61	197	148
Stalk,	absent	71	62
No. of pairs of polyps,	34	54	44
Diameter of rachis,	0·36	...	...
Diameter of stem (at top),	0·32	...	...
Length of fully expanded polyp,	4·5	...	...
„ tentacle,	2·4	...	...
Length of retracted polyp (incl. tentacle),	2	...	...
Size of large spicules of calyx,	2·3 × 0·15	...	...
„ tentacle,	0·13 × 0·02	...	...
Size of spicules of body wall of polyp,	0·56	...	...

Section II. SPICATÆ.

Sub-section 1. *Funiculineæ*.

Family 1. Funiculinidæ.

Funiculina, Lam.

Funiculina quadrangularis, Pall. (Pl. XXIII. fig. 22.)

Ten fragments of this species were obtained by the "Triton" in Loch Linnhe, off Castle Walker, in 35 to 37 fathoms of water, and at a distance of 3¼ miles from the shore.

All the specimens are small and imperfect. Two of them, of 9·4 and 12·5 cm. length respectively, have the stalks perfect, and are broken short above at the lower part of the rachis. The remainder are all mere fragments broken at both ends, and varying in length from 5 to 34 cm..

None of the specimens have the upper ends perfect, a very unusual circumstance with this species, which is usually obtained in perfect condition. The specimens have, however, evidently been roughly handled, and were probably damaged at the time of capture.

All the fragments belong to small and young specimens. Inasmuch as *F. quadrangularis* is found at other parts of Loch Linnhe in great profusion and of large size, specimens having been obtained up to 162 cm. in length, it would appear that the locality from which the "Triton" specimens were obtained is not one favourable to this species.

The portion of rachis of one of the young specimens drawn in fig. 22 shows some points of interest. In the first place, it will be noticed that the calcareous spicules, which in *F. quadrangularis* are usually confined to the calyx, here extend down the whole length of the polyps along the lines of attachment of the septa. These spicules, which also occur in the rachis, though in smaller numbers, have an average length of 1·7 mm. The unusual abundance of these spicules, and their presence in such young specimens, are points of interest.

The middle polyp of the figure is shown in a condition of extreme contraction; the tentacles being completely withdrawn within the calyx, the processes of which meet one another so as to form an acutely pointed cone. This figure agrees very closely with one given by KÖLLIKER,* the accuracy of which has been doubted, owing to the shape being so very unlike that of the expanded or half-expanded polyp, and the apparently exaggerated length of the calyx processes.

Fig. 22 shows also the gradual increase in size of the polyps in passing from the dorsal (right-hand surface in the figure) to the lateral surface; also the entirely independent insertion of polyps and zooids—a primitive feature; and the total absence of distinction between the young polyps and the zooids; also the quadrangular shape of the stem.

Sub-section 2. *Junciformes.*

Family 1. Kophobelemnonidæ.

Kophobelemnon, Asbjörnsen.

Kophobelemnon stelliferum var. *durum* (Köll.). (Pl. XXIV. figs. 23–28.)

Thirty-three entire specimens of this species and seven heads (the upper polyp-bearing part of the rachis) were obtained, one of these being from the "Knight Errant" collection, the remainder from the "Triton" one. They were dredged at four different localities, Stations 6, 8, 10, and 11, and at depths varying from 516 to 640 fathoms.

K. stelliferum was first found by O. F. MÜLLER in 1775, near Dröbak, in the Christianiafjord, and described by him in the *Zoologia Danica*, under the name *Pennatula stellifera*. It has been dredged in various parts of the Christiania fjord by LOVEN and by ASBJÖRNSEN,† the latter of whom obtained it in con-

* KÖLLIKER, *op. cit.*, pl. xvii. fig. 153.

† ASBJÖRNSEN, "Beskrivelse over Kophobelemnon Mülleri," *Fauna littoralis Norvegiæ*, Andet Hefte, pp. 81–85, and Tab. 10, figs. 1–8, 1856.

siderable numbers at a depth of about 40 fathoms, and of sizes varying from 20 mm. long, with only a single polyp, to 125 mm. long, with 24 polyps.

A single specimen was obtained by PANCERI from the Bay of Naples,* and during the "Porcupine" expedition two specimens were obtained by CARPENTER and WYVILLE THOMSON† off the N.W. coast of Scotland,—one in 59° 41′ N., and 70° 34′ W., at a depth of 458 fathoms, the other in 59° 34′ N., and 7° 18′ W., and at 542 fathoms depth.

External Characters.—The "Triton" specimens vary much in size, and in the number and arrangement of the polyps. The smallest specimen is 26 mm. long, and has only two polyps; the largest specimen in the collection, the single specimen obtained by the "Knight Errant," is 88 mm. long, and bears 18 polyps.

The general appearance of one of the average specimens of the "Triton" collection is well shown in Pl. XXIV. fig. 23; the specimen being drawn from the dorsal surface, double the natural size.

The rachis, which is somewhat club-shaped, is widest a short distance below its upper end, from which point it tapers upwards to a blunt point. It bears on its dorsal and lateral surfaces the polyps, which are few in number, and of large size. Between the polyps the surface of the rachis is studded on all sides with zooids, excepting a short tract immediately below each of the polyps, which is destitute of zooids.

The stalk (fig. 23, *b*), which forms rather more than half the entire length of the colony, and which is distinguished from the rachis by bearing no zooids, is oval in section, as shown in fig. 27, and of tolerably uniform size along its whole length, except at its lower end, which presents a terminal thin-walled dilatation.

The arrangement of the polyps differs a good deal in different specimens, and it is difficult to make out any definite system. In all cases the uppermost polyps, those nearest the top of the rachis, are the largest, and the lowest ones the smallest. The most usual arrangement is that shown in fig. 23. Here there are six fully developed polyps arranged in two sets, an upper and a lower one, each of three polyps. Of these three, one is inserted in the dorsal surface of the rachis very close to the mid-dorsal line, or actually in it, while the other two are inserted on the sides of the rachis a little way below the dorsal polyp, and not quite opposite one another, the right hand polyp being as a rule a little above the left hand one. The three polyps of each set are of about equal size, but those of the upper set are much larger than those of the lower set. Below the lower set can be seen in many specimens, as in the one figured, a third set of

* PANCERI, "Intorno a due Pennatularii l'uno non per anco trovato nel Mediterraneo, l'altro nuovo del nostro golfo," *Rendiconto dell' Academia delle scienze fisiche é matematiche*, Napoli, Giugno, 1871.

† *Vide* KÖLLIKER, *op. cit.*, p. 306.

very small and as yet rudimentary polyps, arranged in a manner exactly corresponding to the upper sets.

It is clear that this arrangement might also be described by saying that the polyps are arranged in three longitudinal series, one dorsal and two lateral, the members of each series decreasing in size from above downwards, and this is indeed the method usually adopted. I am disposed, however, to prefer the former mode of description, because it seems to me from an examination of a number of specimens, that the three polyps of each set arise simultaneously, or very nearly so, the dorsal polyps being often a little ahead of the lateral ones, and the right lateral polyps appearing sometimes a little earlier than the left ones.

There appears, indeed, to be a fair amount of constancy in the arrangement and order of appearance of the polyps. Of twelve specimens, four had 3 polyps only, which were clearly the three of the upper set; five had 6 polyps arranged as in fig. 23; one had 4 polyps, *i.e.*, the 3 of the upper set and the second dorsal one; and the other two had 4 and 5 polyps respectively arranged in an irregular manner. In specimens with a larger number of polyps than six, it is very difficult to make out any definite plan of arrangement.

Structure of Polyps.—This has been very fully described by KÖLLIKER,* and will not be considered here in any detail. The main points are shown in the figures 24 to 28. The mesoderm is everywhere, both in stalk, rachis, and polyps, of considerable thickness, and has an immense number of calcareous spicules imbedded in it (figs. 27, 28). Each tentacle (figs. 24 and 25) has along its outer surface a prominent rib, made up of closely packed spicules, while smaller ones extend along the pinnules, as first noticed by PANCERI.

The spicules of the tentacular rib, which may attain a size of 0·66 by 0·11 mm., are of the shape shown in fig. 26, and in transverse section in fig. 25.

The polyps project from the rachis nearly at right angles, as shown in fig. 23, and the polyp cavities on reaching the rachis do not stop, but bending down at right angles to their former course, are continued for some distance down the rachis, ending blindly below; the lower part of the stomodæum, and the whole of the organs below the stomodæum being thus contained within the rachis. The greater part of the thickness of the rachis is, in fact, made up of these lower ends of the polyps, which in a transverse section of the rachis will be seen cut at various levels.

Fig. 28 represents such a section. On the left side it cuts one of the lateral polyps longitudinally and horizontally (*cf.* fig. 13); on the right side it cuts the corresponding polyp of that side lower down, the section passing transversely through the lower part of the stomodæum. The dorsal polyp of the set is cut at a still lower level, the section passing through the two long mesenterial filaments and the ova.

* *Op. cit.*, pp. 297–304.

The section also shows four zooids cut, like the polyps, in different planes and at different levels.

Plane of Symmetry.—Each polyp of a Pennatulid colony can be divided longitudinally into two perfectly similar halves by one plane only, which is spoken of as the plane of symmetry. This plane passes between the two long mesenterial filaments, bisecting the septal chamber bounded by the two septa which bear these filaments; it also bisects the septal chamber immediately opposite to this one, and passes along the long axis of the stomodæum, which in transverse section (fig. 28, *s*) is oval, not circular in shape. In *Kophobelemnon* this plane of symmetry of each polyp has a very definite relation to the rachis. The plane is a vertical one, and is perpendicular to the surface of the rachis to which the polyp is attached, so that if prolonged it would pass through the centre of the calcareous axis or stem. These relations will become more obvious from an inspection of fig. 28. In the case of all three polyps shown in this figure, the planes of symmetry, being vertical when the specimen is placed upright in its natural position, will be at right angles to the plane of the paper. In the case of the dorsal polyp the plane of symmetry must pass through the centre of the polyp cavity, and must also (by definition) pass midway between the two long mesenterial filaments *p*; it is obvious from this figure that this plane, if prolonged, will pass through the centre of the calcareous stem *c*.

So also in the case of the right hand polyp of the figure. In order to divide the retractor muscles *rm* symmetrically, it is clear that the plane of symmetry must bisect the septal chamber next to the stem *c*, and also the chamber immediately opposite to this one; such a plane will pass along the longer axis of the stomodæum *s*, and will, if prolonged, pass through the centre of the stem *c*.

So with all the other polyps, the plane of symmetry will always be a vertical one, will be at right angles to the surface of the rachis at the point of insertion of the polyp, and will, if prolonged, pass through the centre of the calcareous stem.

It is further evident from fig. 28 that the two long mesenterial filaments are on the side of the polyp next to the stem, so that the surface of the polyp which, when the polyp becomes free from the rachis (*cf.* fig. 23), is continuous with its upper surface, may conveniently be called the *axial surface;* while the opposite surface, which is furthest from the stem, and which is continuous with the lower surface of the polyp when this becomes free from the rachis, may be called the *abaxial surface.*

I have already used the terms *axial* and *abaxial* when describing the surfaces of the *Pennatula* zooids,* and have done so in exactly the same sense

* *Supra*, p. 125.

as that here proposed, the *axial* surface being that which bears the long mesenterial filaments. As these words express a real and an important relation, they would appear preferable to the very misleading terms *dorsal* and *ventral*, which are commonly employed to denote the surfaces in question.

The plane of symmetry of the zooids obeys exactly the same laws as that of the polyps, the mesenterial filaments being placed on the axial wall.

Concerning the arrangement of the zooids on the rachis, it will be seen from fig. 28 that the reason of the existence of a short tract devoid of zooids immediately below each polyp is that this tract is really part of the *abaxial* wall of the polyp; and as the zooids are developed on the rachis itself and not on the polyps, there can clearly be no zooids on these tracts.

Retraction of Polyps.—In spite of the great rigidity of the wall both of the polyp itself and its tentacles, due to the enormous number of spicules contained in it, the polyps can, as shown on the right-hand side of fig. 23, be withdrawn almost completely into the rachis, the tentacles entirely disappearing from sight in the fully retracted state. During the process of retraction the body wall of the polyp is thrown into transverse folds, and one specially deep fold at the junction of body and tentacles (*vide* the left-hand polyp of fig. 28) corresponds to the calyx of other Pennatulida.

Structure of Stalk.—This is well shown in fig. 27, representing a transverse section taken about the middle of its length. The mesoderm is of great thickness, and is divided into inner and outer zones by the well-developed layer of longitudinal muscles *lm*, which forms a deeply corrugated sheath extending round the whole stalk. Of the two zones the outer one is very richly studded with calcareous spicules *i*, crossing one another in all possible directions; while the inner zone is devoid of spicules, and is traversed by a dense network of nutrient canals. The stem *c* is quadrangular, with rounded angles and grooved lateral surfaces. In the rachis, as we have seen (fig. 28), the stem is cylindrical; but this change in shape is by no means exceptional, occurring in *Pennatula* and several other genera, as well as in *Kophobelemnon*.

The stem is invested by a mesodermal sheath, which is prolonged outwards to the body wall as four vertical septa, which separate from one another the four main longitudinal canals of the stalk, of which the dorsal *dc*, and ventral *vc*, are considerably larger than the lateral ones *lc*. If these canals, which are lined by endoderm, be traced upwards towards the rachis, the two lateral ones are soon found to disappear; the dorsal one extends a short distance up the rachis, and then in its turn disappears, while the ventral one (fig. 28, *vc*) persists of considerable size throughout the whole length of the rachis.

Of *Kophobelemnon stelliferum* Köllikер* distinguished at first two varieties, which he named *mollis* and *dura* respectively, the difference consisting chiefly

* Köllikер, *op. cit.*, p. 305.

in the greater number and size of the spicules of the latter, which reach in the tentacles a length of from 0·64 to 0·89 mm. and width of 0·09 to 0·12 mm. The muscular layers are also far less strongly developed in the var. *dura* than in var. *mollis*.

At a later period* he described a specimen from the Atlantic at a depth of 690 fathoms, which was in all its characters intermediate between the two other forms, and seemed to prove them to be merely varieties, and not, as once supposed, specifically distinct.

The "Triton" specimens belong clearly to the variety *dura*, though they differ a good deal among themselves as to the size of the spicules. The single specimen from the "Knight Errant" collection has much smaller spicules than any of the others, and is to be referred to the variety *intermedia*.

The following table gives the measurements of the "Knight Errant" specimen and of one of the typical "Triton" specimens :—

	A. Var. *intermedia* from "Knight Errant."	B. Var. *dura* from "Triton."
Total length, . . .	82 mm.	45 mm.
Length of rachis, . .	43·5	21
„ stalk, . .	38·5 (broken at lower end)	24
No. of polyps, . . .	18	6
Size of spicules (largest), .	0·31 × 0·018	0·66 × 0·11

All the specimens of *K. stelliferum* were encrusted rather thickly with sand, which adhered somewhat firmly to the ectoderm, and doubtless acted in part as a protective envelope. The internal cavities, both stomodæum, body cavity, and tentacular cavities, also contained large quantities of sand, which rendered the preparation of sections a matter of some difficulty. Whether this indicates a habit of retraction into the sand in which they live planted by their stalks, or whether the sand is purposely swallowed for the sake of food matters that may be mixed with it, I have had no opportunity of determining.

Family 2. Umbellulidæ.

Umbellula, Lam.

Umbellula gracilis, n. sp. (Pl. XXV. figs. 29–35.)

Specific Characters.—Distinctly bilateral. Polyps forming a cluster on the upper end of a club-shaped rachis ; greyish in colour with dark reddish-brown tentacles. Stalk long, very slender and exceedingly flexible ; ending below in a dilated vesicular portion. Zooids numerous on the rachis between the polyps,

* *Op. cit.*, p. 320.

and extending a short distance below them; zooids of upper part of rachis much the largest, and each provided with a tentacle bearing a double row of pinnules; zooids of lower part of rachis are smaller,—they may have tentacles, but these do not bear more than a single pinnule. Stem cylindrical along the greater part of its length, becoming quadrangular in the terminal dilated part. No calcareous spicules at any part of the colony.

Habitat.—Station 11; depth 555 fathoms.

External Characters.—A single specimen of this species was obtained with the trawl. This specimen, which is in perfect condition, is represented of the natural size, and from the dorsal surface in Pl. XXV. fig. 29. It has a total length of 290 mm., of which the upper 26 mm. are expanded to form the club-shaped rachis. This ends above in a blunt point (fig. 30), and is widest about the middle of its length, where it measures 6 mm. from side to side, and 5 mm. from the dorsal to the ventral surface.

The rachis bears the polyps on the upper two-thirds of its length, and below the lowest polyp tapers somewhat rapidly, and passes without any sharp line of demarcation into the stalk.

The stalk is cylindrical and very slender, with a diameter about the middle of its length of 0·8 mm. At its lower end it presents a distinct enlargement, 35 mm. long and 3·5 mm. in diameter. For the greater part of its length the stalk is extremely flexible, so much so that it can readily be coiled in circles of 5 mm. diameter without the slightest danger of breaking.

The stem or calcareous axis is cylindrical along the greater part of the length of the stalk, with an average diameter of 0·5 mm. Shortly before reaching the terminal dilatation of the stalk the stem enlarges somewhat suddenly to 0·9 mm. in diameter, becoming at the same time quadrangular in shape, and very much more rigid than in the upper part. In the terminal dilatation it gradually tapers towards the lower end.

The polyps, which are confined to the upper 18 mm. of the rachis (figs. 29 and 30) are 13 in number, and gradually increase in size from above downwards. They are inserted on all sides of the rachis, with the exception of a narrow strip 1·5 mm. wide along the mid-ventral surface (fig. 30), and even this is somewhat encroached upon by the lowest polyps.

It is difficult to make out any definite plan of arrangement of the polyps. Commencing at the top, the first polyp, which is the smallest of the lot, is inserted in the left latero-dorsal surface just below the apex. The second polyp is placed on the right latero-dorsal surface, a little way below the first. Then comes a rather irregular whorl of six polyps, of which two are dorsal, two lateral, and two latero-ventral; and finally a lower whorl of five polyps, the largest of all, of which one is mid-dorsal, two lateral, and two latero-ventral, the left one of the last pair almost reaching the mid-ventral line.

The body of the polyp is greyish in colour, and from 10 to 15 mm. in length. It is widest at its base—4 mm. in the larger polyps, and gradually narrows in its upper third to 2·5 mm. The upper part is marked by very distinct longitudinal grooves opposite the septal attachments, and is also slightly corrugated transversely.

The tentacles are of a dark reddish-brown colour, and of about the same length as the polyp body. Each is fringed by a double row of pinnules, which exhibit an irregular alternation of larger and smaller ones (fig. 31); the larger pinnules being inserted rather nearer the inner or oral surface of the tentacle than the small ones. LINDAHL* has directed special attention to this inequality of the pinnules in the case of *U. Lindahli* (Köll.)†, where it appears to be much more marked than in *U. gracilis*.

The polyps and tentacles are non-retractile, or can at most be withdrawn to a very slight extent, and there is no trace of a calyx.

Structure of Polyp.—One of the polyps was removed for the sake of studying its structure, and cut into a series of transverse sections. The anatomy presents no points of special importance. The body wall is of only moderate thickness, the body cavity and tentacular cavities being of large size. As in *Kophobelemnon* the polyp cavities are prolonged into the rachis, but a larger proportion of the polyp is free than in this genus; the stomodæum and upper part of the mesenterial filaments being contained within the free part of the polyp, and the reproductive organs and lower part of the mesenterial filaments being alone situated within the rachis.

The plane of symmetry in the case of the one polyp examined, and presumably in the others as well, obeys the same laws that have been found above to apply to *Kophobelemnon* and *Pennatula*, *i.e.*, it is vertical and at right angles to the surface of the rachis at the point of insertion of the polyp. The axial surface of the polyp, moreover, is that which bears the two long mesenterial filaments.

The single specimen obtained is a female, and the arrangement of the reproductive organs is the same as in other *Pennatulida*, the ovaries being the free edges of the six septa which bear, higher up, the six short mesenterial filaments. Fig. 34 represents a section of one of these fertile septa and of the part of the body wall from which it springs. The figure shows the largely developed retractor muscle of the polyp *rm*, and at the edge of the septum ova in various stages of development, each with a large nucleus and nucleolus, and invested in a distinct epithelial capsule. The ripe ova have a diameter of 0·1 mm.

* LINDAHL, "Om Pennatulid-slägtet Umbellula," *Kongl. Svenska Vetenskaps-Akademiens Handlingar*, Bd. xiii. No. 3, Stockholm, 1874.

† KÖLLIKER, *Die Pennatulide Umbellula*, Wurzburg, 1875. KÖLLIKER proposes to group together LINDAHL'S *U. miniacea* and *U. pallida* under the name *U. lindahli*.

The specimen being in excellent histological condition, I have been enabled to make some observations on the development of the ova. Fig. 35 represents a transverse section through one of the ovigerous septa close to its free inner edge. The septum is seen to consist of a central mesodermal lamella *x*, clothed on each side by a thick layer of endodermal cells *y*. Of these cells the superficial ones form a layer of short columnar or cubical cells, while the remainder of the endoderm consists of larger cells of irregular polygonal shape, closely packed together, with large granular but rather ill-defined nuclei and granular protoplasm.

Among these cells certain ones are conspicuous by their larger size and granular appearance, *o'*. These, which are the germinal cells or primitive ova, appear to arise in the deeper parts of the endoderm layer close to the mesoderm lamella, and as they increase in size gradually move outwards towards the surface.

Together with this increase of size the ova become spherical in shape, the protoplasm becomes very granular and opaque, and the nucleus, which at first was an ill-defined granular body, becomes vesicular, and acquires a distinct nucleolus and a very well-marked nuclear reticulum. In some of the larger ova *o*, a reticular appearance is also evident in the protoplasm.

The ovum, by its continued growth, reaches the surface of the septum, and pushing before it the surface layer of columnar epithelium, which forms the follicular investment, projects freely from the surface to which it remains attached by a short stalk (fig. 34).

In *Sagartia*, according to the HERTWIGS,* the ova arise in the deeper layer of the endoderm, but sink into and become invested by mesoderm before commencing their outward passage towards the surface of the ovary. I have seen no trace of such a mesodermal investment in *Umbellula*, neither have I seen the peculiar polar fibrillar apparatus described in *Sagartia*.

Structure of Zooids.—The zooids of *U. gracilis* are unique among Pennatulida, so far as at present known, in possessing pinnated tentacles.

As shown in fig. 30, the zooids cover all parts of the rachis not occupied by the polyps. The largest zooids are those at the upper end of the rachis, and it is in this situation alone that the zooids with pinnated tentacles occur. Below the polyps the zooids get gradually smaller and smaller.

Fig. 32 represents on a larger scale a group of zooids from the ventral surface of the upper extremity of the rachis, drawn with the camera. The zooids are seen to be conical, in the best marked cases tubular, projections with a mouth at the free end overhung by a single tentacle, which bears a variable number of pinnules. The pinnules may occur on one side only or on both, and in some cases form a row of five or six on each side of the tentacle.

* O. und R. HERTWIG, *Die Actinien*, pp. 95 *seq.*

In fig. 33 one of these zooids is represented in longitudinal vertical section, together with the part of the rachis from which it springs.

The tentacle, which is hollow, overhangs the mouth on the abaxial side, a point of some interest, inasmuch as the calycular processes of the large ventral zooids of *P. phosphorea* var. *aculeata* were also found to be abaxial (*cf.* Pl. XXII. fig. 8).

The mouth *n* leads into the stomodæum *s*, the abaxial wall of which is clothed with very long cilia *r*. At its lower end the stomodæum opens into the body cavity *h*, which is lined by endoderm, and is prolonged into the tentacle. The body cavity is, at any rate in some cases, in direct communication with that of adjacent zooids.

As in zooids generally, there are only two mesenterial filaments present, of which one is shown in the figure. These are borne by the axial septa, and are extremely long and much convoluted.

In some of the larger zooids I have noticed a slight notching of the margin of the mouth, which may possibly indicate the rudiments of additional tentacles.

Below the polyp-bearing part of the rachis the zooids become much smaller. The tentacles at first increase slightly in length, but become much more slender, and lose their pinnules, with the exception of a single one, which is often retained, giving a bifid appearance to the tentacle. These tentaculiferous zooids are, as shown in fig. 30, almost confined to the lateral margin of the rachis, the zooids of the dorsal and ventral surface becoming very early reduced to the condition of small wart-like knobs. These become smaller in size and more irregular in arrangement as we pass downwards, and finally cease about 50 mm. from the upper end of the rachis.

In possessing single tentacles the zooids of *U. gracilis* resemble those of *U. Huxleyi* and *U. Carpenteri*,* two of the species obtained by the "Challenger" from the North Pacific and South Polar seas respectively, but differ from all other species, and indeed from all other Pennatulida yet described. In possessing pinnated tentacles the zooids of *U. gracilis* stand absolutely alone.

I have pointed out above, when discussing the nature of the zooids of *P. phosphorea*, that zooids must be considered as abortive polyps arrested in an early stage of development.

It becomes now an interesting inquiry how this unitentacular condition of the zooids of *Umbellula* arose. So far as is at present known, the earliest rudiments of all eight tentacles arise simultaneously in the Pennatulid polyps. I have described this above in the case of the asexually formed polyps of *Pennatula*

* Kölliker, *Zool. Chall. Exp.*, part ii. 1880, pp. 21–24.

and *Virgularia*, and WILSON * has recently shown that the same applies to the sexually produced young of *Renilla*. It appears, therefore, that the unitentacular condition of the Umbellula zooid is not a repetition of any stage occurring in the ontogeny of the normal Pennatulid polyp. It is, however, just possible that such a stage once existed in the phylogeny of the group, but has dropped out of its ontogeny. So far as is known, a unitentacular condition does not obtain in the ontogeny of any Alcyonarian, though we must bear in mind that very few forms have as yet been studied adequately. Among Zoantharia a temporary unitentacular condition occurs in *Actinia mesembryanthemum*,† while in *Cerianthus* and *Arachnitis* four tentacles arise simultaneously, and in other cases all eight.

The definite relation of the single tentacle of the *Umbellula* zooid to the plane of symmetry seems to indicate that it has some morphological significance, though at present we have not evidence to determine what that significance is. I would, in conclusion, direct attention to the remarkable condition of the polyps in *Scytalium tentaculatum*, Köll.,‡ one of the "Challenger" species, in which each polyp has but a single tentacle, as showing that a unitentacular condition may be more widely spread than is at present suspected.

Our knowledge of the genus Umbellula has been very greatly increased of late years. Two specimens taken off the coast of Greenland in 1752, and very imperfectly described, were for more than a century the only examples recorded. In 1871 LINDAHL obtained two specimens, one in Baffin's Bay in 410 fathoms, and the other at the entrance to the Omenakfjord, in N. Greenland, at a depth of 122 fathoms. An *Umbellula* was also obtained by NORDENSKIÖLD in the Kara Sea, to the east of Novaya Zemlya, during the "Vega" expedition.

The "Challenger" expedition added enormously to our knowledge of this genus, no less than seven new species being obtained from widely different parts of the world. Concerning the geographical distribution of this genus KÖLLIKER says:—"After having known for more than a century only one locality, the North Polar Sea, near the coast of Greenland, we have now learned that this form is far and widely distributed. *Umbellulæ* have now been obtained from the North Atlantic Ocean (between Portugal and Madeira); from the North Polar Sea, coast of Greenland; from the Atlantic Ocean, under the Equator, between Africa and America, and from the west coast of Africa, north of Sierra Leone (Stud.); from the South African Sea, west of Kerguelen Island; from the South Polar Sea; from the coasts of New Guinea and of

* WILSON, "The Development of Renilla," *Proc. Roy. Soc.*, 1882.

† LACAZE-DUTHIERS, "Développement des Coralliaires," *Archives de Zoologie expérimentale et générale*, vol. i. 1872, and vol. ii. 1873.

‡ KÖLLIKER, *Zool. Chall. Exp.*, part ii., 1880, pp. 10, 11, and pl. iii. fig. 12, pl. iv. fig. 13.

Japan; and from the middle of the North Pacific Ocean. *Umbellula* has, therefore, of all genera of Pennatulida, the widest distribution."*

The "Triton" specimen makes a very interesting addition both to the list of species of *Umbellula* and to the localities in which it has been found.

The measurements of the sole specimen of *Umbellula gracilis* yet known are as follows:—

Total length,	290 mm.
Length of rachis (dilated part),	26
Length of polyp-bearing part of rachis,	18
Width of rachis at widest part,	6
Thickness,	5
Length of terminal dilatation of stalk,	35
Diameter,	3·2
Diameter of stalk (middle of length),	0·7
„ stem,	0·5
„ stem (widest part),	0·9
Number of polyps,	13
Length of polyp (shortest),	15
„ body,	7·5
„ tentacle,	7·5
Length of polyp (largest),	26
„ body,	13
„ tentacle,	13
Diameter of polyp, base,	5
„ just below tentacles,	2·8
Length of zooid, largest,	1·8
Length of tentacle of zooid, largest,	1·3

General Observations.

Geographical Distribution.

Horizontal Distribution.—The most noteworthy point is the great abundance and variety of specimens dredged at one particular locality,—Station 11. At this place there were obtained, from a depth of 555 fathoms, nineteen specimens of *Pennatula phosphorea* var. *aculeata;* three specimens of *Virgularia tuberculata*, a new species; one specimen of *Dübenia abyssicola* var. *smaragdina*, a form hitherto found only off the Norwegian and Swedish coasts; thirty specimens of *Kophobelemnon stelliferum* var. *dura;* and one specimen of *Umbellula gracilis*, a new species; *i.e.*, example of five out of the fourteen known families of Pennatulida, of three distinct subsections, and two of the four sections of the order were obtained at this one spot.

* Kölliker, *Zool. Chall. Exp.*, part ii. 1880, p. 37.

This extraordinary profusion mark the locality as a very exceptional one. At each of the other stations only single species were obtained.

Vertical Distribution.—The "Triton" observations have increased the vertical range of *Pennatula phosphorea* to 555 fathoms, its previously recorded limit being 340 fathoms; of *Dübenia abyssicola*, from 120 to 555 fathoms; of *Kophobelemnon stelliferum* v. *durum*, from 300 to 640 fathoms; and have added a new deep water *Virgularia*, *V. tuberculata*, extending to 555 fathoms, to the sole one previously known, *V. bromleyi*.

These results, so far as they go, do not lend any very material support to KÖLLIKER's conclusion, that "the simpler forms of Pennatulida, especially those with sessile polyps, inhabit great depths."*

KÖLLIKER ranks among primitive forms of Pennatulida the *Umbellulidæ*, which are an essentially deep water family, seven out of the twelve known species being found below 1000 fathoms and five below 1800 fathoms, and cites this distribution in evidence of the view that the lower forms of Pennatulida are, as a rule, deep water forms.

Umbellula appears to me, however, to be not a primitive form but a highly modified one. This is shown by the great length of the non-polypiferous as compared with the polyp-bearing part of the colony, *i.e.*, the great preponderance of the purely colonial portion; by the great difference between the polyps and the zooids; by the extreme differentiation of some of the zooids; and, above all, by the polymorphism of the zooids themselves, an almost unique condition among Pennatulids. In all these respects *Umbellula* is far less primitive than *Funiculina*, which is essentially a shallow water form, attaining its maximum of development at about 30 fathoms depth.

A point of considerable interest concerns the influence of increase in depth on the structure and habits of Pennatulids. On this point but little can be said at present for want of sufficient evidence.

We have seen above that some of the deep water forms (below 500 fathoms) have much thicker body walls and layers, and more numerous spicules, than those from less depths. If we compare different genera together there would appear to be no relation whatever between depth of water and development of spicules; thus *Umbellula gracilis* and *Virgularia tuberculata* from 555 fathoms have no spicules at all; while *P. phosphorea* and *K. stelliferum*, brought up in the same dredge with the preceding species, have exceptionally large and numerous spicules. If, however, we confine ourselves to one species, we seem to find such a relation; thus the specimens of *Pennatula phosphorea* from below 500 fathoms have very much thicker walls, and larger and more abundant spicules, than those from 20 to 40 fathoms. In this case we have strong reason

* KÖLLIKER, *Zool. Chall. Exp.*, part ii. 1880, p. 39.

for thinking, from the small size and somewhat stunted appearance of the deep water specimens, that the species is typically a shallow water one, and it is very possible that the increase in development of spicules is due directly to the change of environment.

All the specimens of *Kophobelemnon* and also those of *Pennatula* obtained below 500 fathoms contain large quantities of sand mixed with Foraminifera shells, both in the polyp cavities and in the tentacular cavities, and also encrusting the exterior. The specimens of *Umbellularia, Dübenia,* and *Virgularia* brought up at the same time are, however, perfectly clean and free from sand. Whether this indicates difference in habits or is merely accidental, I have no means of ascertaining; the specimens of *Pennatula* from shallow water have no sand in the polyp cavities, or but very little.

Morphology.—The chief points of morphological interest on which light is thrown by the "Triton" specimens appear to concern the structure of the zooids of *Pennatula* and *Umbellula;* and the relations of the plane of symmetry of the polyps established in *Pennatula, Kophobelemnon,* and *Umbellula.*

DESCRIPTION OF THE FIGURES ON PLATES XXI.—XXV.

All the figures were drawn with the camera. Figures 8, 28, and 33 are not taken from single sections, but are constructed from a number of separate camera drawings of the several parts shown. The numbers beneath the figures indicate in diameters the magnifying power employed in each case.

Alphabetical List of References.

a, rachis.
b, stalk.
c, stem.
d, polyp.
dc, main dorsal canal of rachis.
dl, leaf.
e, zooid.
f, large zooid.
g, body cavity of polyp.
h, body cavity of zooid.
i, spicule.
k, spicular plate.
l, calyx process.
l', cavity of calyx process.
lc, main lateral canal of rachis.
lm, longitudinal muscles of rachis and stalk.
m, mesentery or septum.
n, mouth.
o, ovum.
o', germinal cell or primitive ovum.
p, long mesenterial filament.
r, cilia of siphonoglyphe.
rm, retractor muscle of polyp.
s, stomodæum.
t, tentacle.
t', cavity of tentacle.
u, pinnule of tentacle.
v, spermatosphere.
vc, main ventral canal of rachis.
w, ectoderm.
x, mesoderm.
x', nutrient canals of mesoderm.
y, endoderm.

Plate XXI.

Fig. 1.—*Virgularia tuberculata;* ventral surface. × 3.

Fig. 2.—*Virgularia tuberculata;* portion of rachis, ventral surface, showing arrangement of polyps in groups of threes; also the tubercular calyx processes and the varying conditions of the calyx during retraction of the polyp. × 17.

Fig. 3.—*Virgularia tuberculata;* two spermatospheres from lower part of rachis of the specimen shown in fig. 1. × 70.

Fig. 4.—*Pennatula phosphorea* var. *aculeata;* from right side. Shows characteristic shape of leaves, also both small and large zooids. × 2.

Fig. 5.—*Pennatula phosphorea* var. *aculeata;* transverse section of rachis with one entire leaf and the base of the corresponding one of the other side. Shows shape of leaf; shape and arrangement of zooids both large and small; great thickness of wall of rachis, and small size of its main canals. × 4.

Fig. 6.—*Pennatula phosphorea;* transverse section of rachis with entire leaf of normal form, for comparison with fig. 5. Shows great width of leaf, absence of large zooids, thinness of walls of rachis, and large size of main canals. × 4.

Fig. 7.—*Pennatula phosphorea* var. *aculeata;* lower end of rachis from left side. Shows stages in development of polyps, and especially the simultaneous appearance of the calyx processes and of the tentacles; also the primitive independence of the polyps of one another. × 17.

Plate XXII.

Illustrating the anatomy of the large ventral zooids of *Pennatula phosphorea* var. *aculeata.*

The reference letter l^1 in the figures on this plate should be l^1.

Fig. 8.—Longitudinal section of large ventral zooid and of the part of the rachis from which it arises. Shows structure of large zooid and of one of the small zooids. × 50.

Fig. 9.—Transverse section of a calyx process of a polyp, for comparison with the succeeding figure. × 150.

Figs. 10 to 16.—Transverse sections through one of the large ventral zooids at various parts of its height, fig. 10 being close to the apex and fig. 16 at the base of attachment to the rachis. × 150.

Fig. 10.—Through upper end of zooid, showing one calycular cavity.

Fig. 11.—Lower down; shows two calycular cavities.

Fig. 12.—Lower down still; shows three calycular cavities.

Fig. 13.—Through upper part of mouth; shows long cilia of siphonoglyphe.

Fig. 14.—Through lower part of mouth; shows five calycular cavities.

Fig. 15.—Through stomodæum about the middle of its length. Shows eight septa and septal chambers.

Fig. 16.—Through lower part of polyp cavity, showing the two mesenterial filaments, and the remains of the other six septa.

Plate XXIII.

Fig. 17.—*Dübenia abyssicola* var. *smaragdina.* Ventral surface. × 3.

Fig. 18.—*Dübenia abyssicola* var. *smaragdina.* Portion of rachis from left side. Shows arrangement of polyps in pairs, each pair embraced at base by a fan-shaped spicular plate. × 17.

Fig. 19.—*Dübenia abyssicola* var. *smaragdina*. Portion of rachis from dorsal surface. Shows arrangement of polyps and zooids. × 17.

Fig. 20.—*Dübenia abyssicola* var. *smaragdina*. Tentacle of polyp, showing rib of calcareous spicules. × 70.

Fig. 21.—*Dübenia abyssicola* var. *smaragdina*, one of large spicules of spicular plate. × 55.

Fig. 22.—*Funiculina quadrangularis*. Portion of rachis of young specimen from left side. Shows shape of polyp in state of extreme contraction; also extension of spicules down whole length of polyps and on to rachis. × 7.

Plate XXIV.

Kophobelemnon stelliferum var. *durum*.

Fig. 23.—Whole specimen, dorsal surface; showing typical arrangement of polyps. × 2.

Fig. 24.—Tentacle of polyp; showing rib of calcareous spicules extending whole length of tentacle and along pinnules. × 20.

Fig. 25.—Transverse section of tentacle, showing tentacular cavity and extension into pinnules, also arrangement and shape of spicules. × 70.

Fig. 26.—Two large spicules from spicular rib of tentacle. × 55.

Fig. 27.—Transverse section of stalk; showing arrangement of spicules and muscles; also shape of stem and of main longitudinal canals. × 30.

Fig. 28.—Transverse section of rachis passing through three polyps at different portions of their length. The left-hand polyp is cut horizontally (*cf.* fig. 23), and shows stomodæum, mouth, and tentacles; the right-hand polyp is cut transversely through the lower portion of the stomodæum, and shows arrangement of retractor muscles and position of plane of symmetry of polyp; the third or dorsal polyp is cut transversely at a still lower level, and shows the two mesenterial filaments and a number of ova. The section also shows several zooids and the shape and position of the stem and of the main ventral canal. × 30.

Plate XXV.

Umbellula gracilis.

Fig. 29.—Whole specimen; dorsal surface. × 1.

Fig. 30.—Rachis; ventral surface. Shows arrangement of polyps and zooids. × 2.

Fig. 31.—Tentacle of polyp; shows alternation of large and small pinnules. × 10.

Fig. 32.—Apex of rachis; ventral surface. Shows shape and arrangement of large zooids with pinnate tentacles. × 14.

Fig. 33.—Longitudinal section of one of the large zooids; shows the tentacle with its pinnules, mouth, stomodæum, mesenterial filament, &c. × 55.

Fig. 34.—Section of septum bearing ova, and of the part of the body wall of the polyp from which the septum arises. Shows also the disposition of the retractor muscle. × 70.

Fig. 35.—Section of ovigerous septum close to its free edge, showing various stages in the early development of the ova. × 470.

Fig. 1.
X 3



Fig. 5.
X 4



Fig. 6.
X 4.

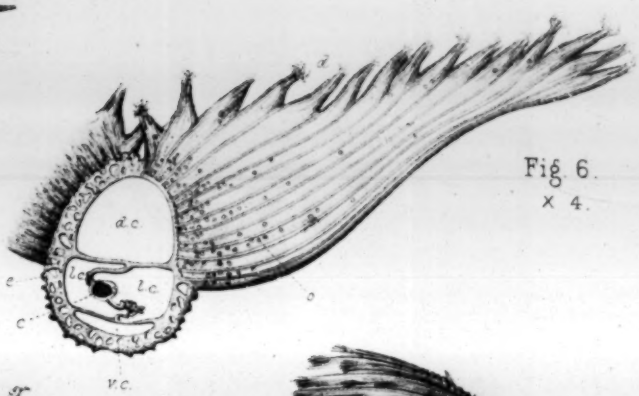


Fig. 2.
X 17

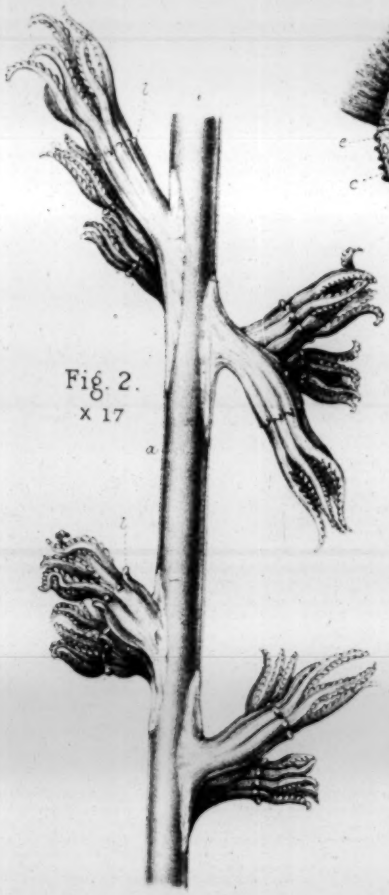


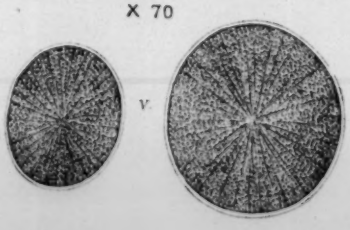
Fig. 4.
X 2



Fig. 7.
X 17



Fig. 3.
X 70



A.M. Marshall del. ad nat.

VIRGULARIA. PENNATULA.

Fig. 8.
× 50

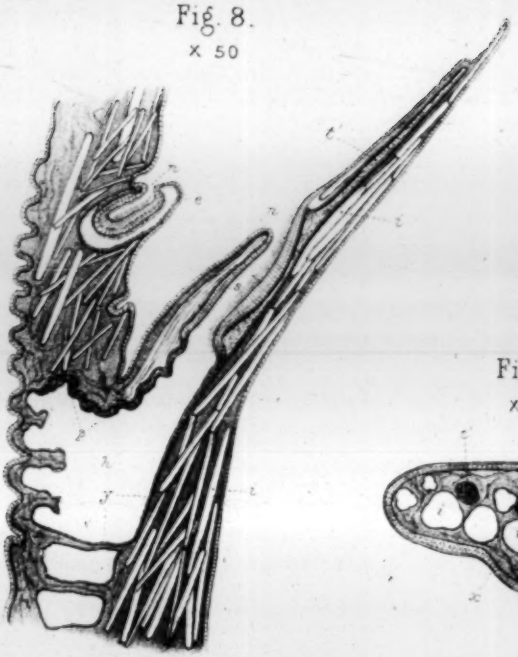


Fig. 9.
× 150



Fig 10.
× 150

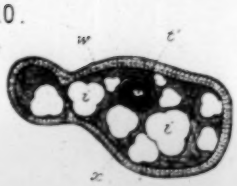


Fig. 11.
× 150



Fig. 12.
× 150

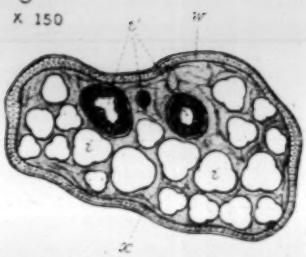


Fig. 13.
× 150

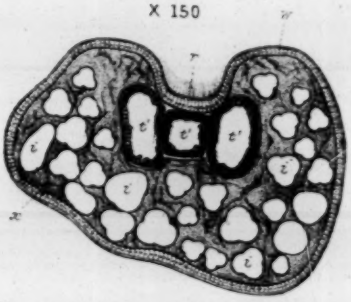


Fig. 14.
× 150

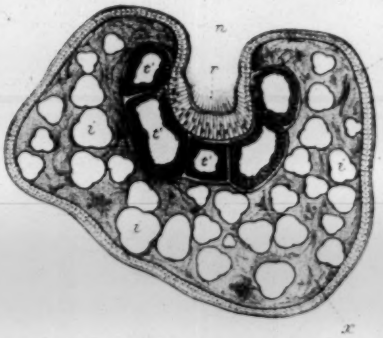


Fig. 15.
× 150

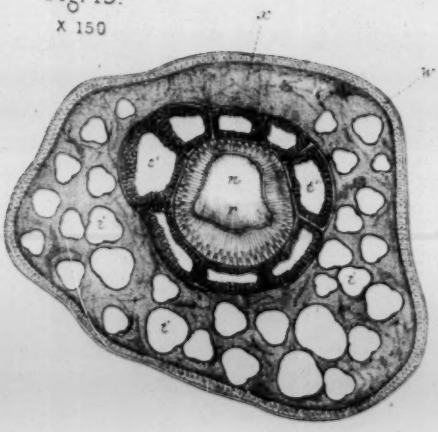
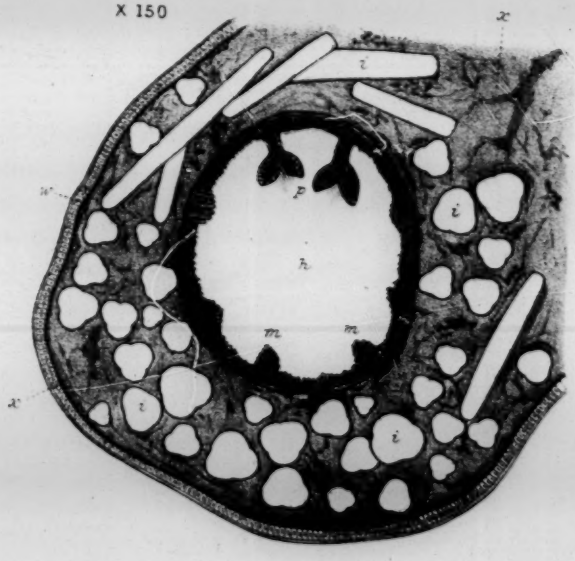


Fig. 16.
× 150



A.M. Marshall del. ad nat.

F. Huth, Lith.r Edin.r

PENNATULA.

Fig. 17.
× 3



Fig. 18.
× 17



Fig. 19.
× 17



Fig. 20.
× 70



Fig. 21.
× 55

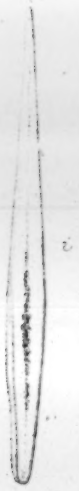
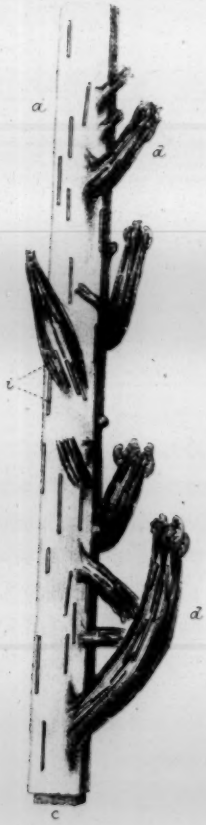


Fig. 22.
× 7



A M Marshall del. ad nat.

DÜBENIA. FUNICULINA.

T Huth, Lith.r Edin.r

Fig. 23.
x 2

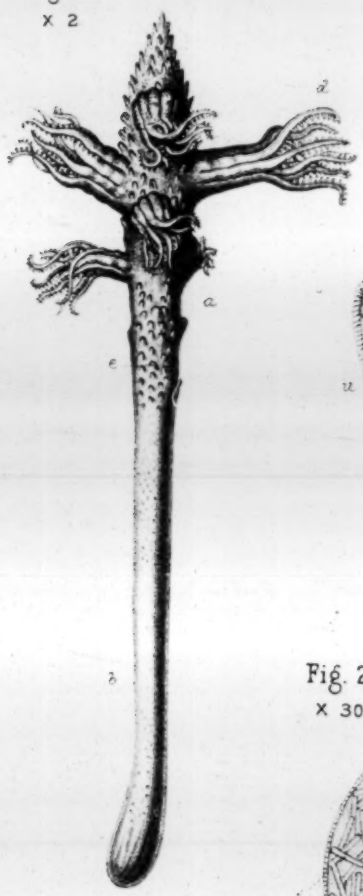


Fig. 26.
x 55



Fig. 24.
x 20



Fig. 25.
x 70

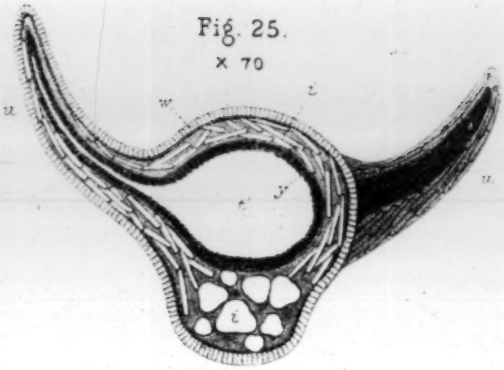


Fig. 27.
x 30

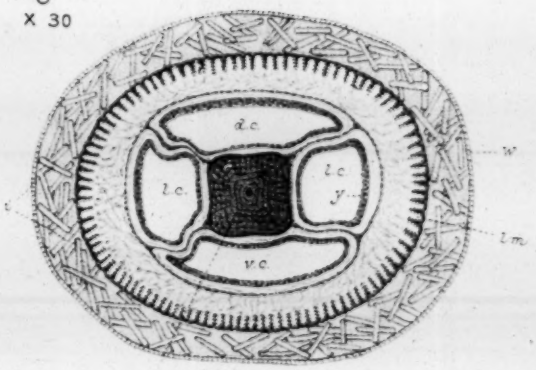
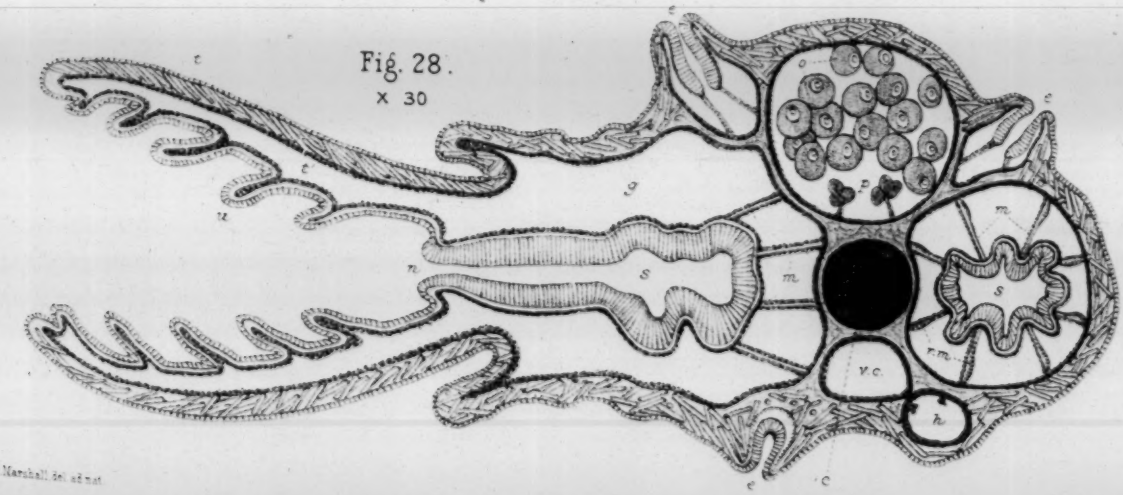


Fig. 28.
x 30



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J. Roth. Lith. Edin.ª

KOPHOBELEMNON.



Fig. 29.
× 1

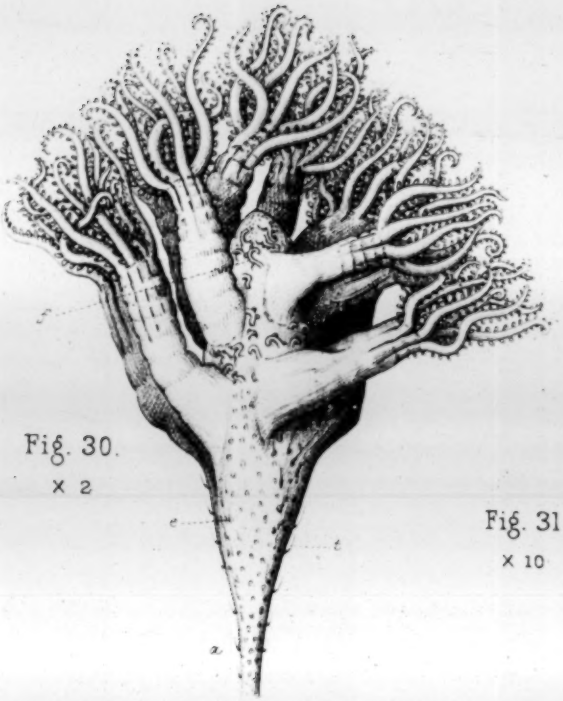


Fig. 30.
× 2

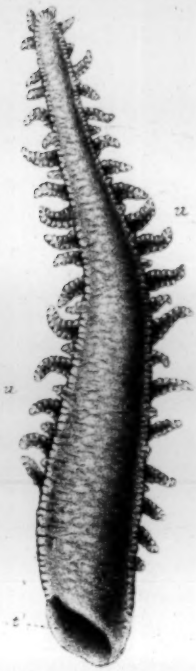


Fig. 31.
× 10

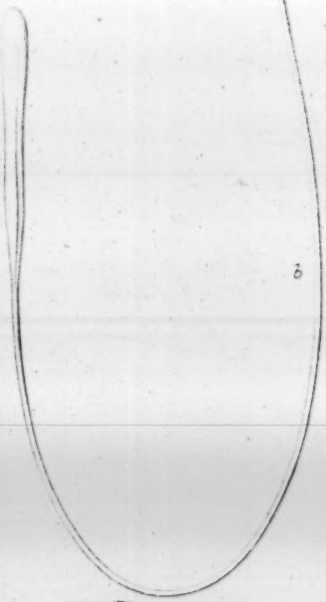




Fig. 32.
× 14.

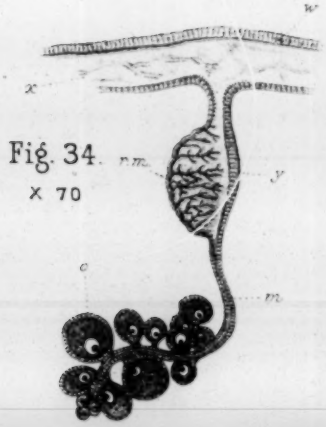


Fig. 34.
× 70

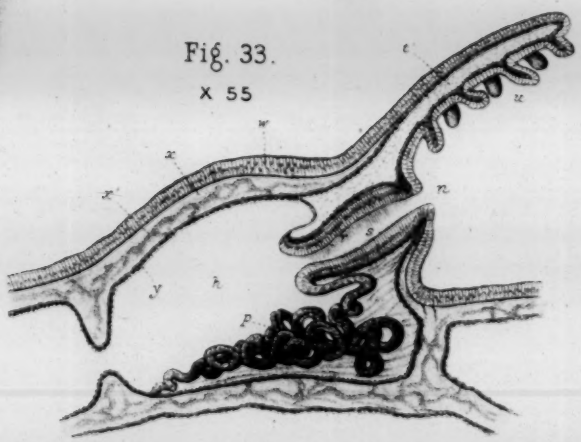


Fig. 33.
× 55

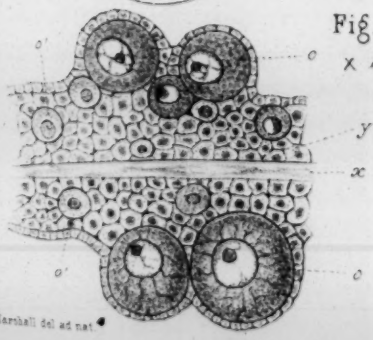


Fig. 35.
× 470

A.M.Marshall del. ad nat.

P. Heath, Lith.ª Edin.ª

UMBELLULA.

IX.—*Asteroidea dredged in the Faeröe Channel during the Cruise of H.M.S. "Triton" in August* 1882.

By W. Percy Sladen, F.L.S., F.G.S. Communicated by John Murray, F.R.S.E. (Plate XXVI.)

(Read 16th July 1883.)

The star-fishes recorded in the present communication were dredged by Mr John Murray during the cruise of H.M.S. "Triton" (under the command of Staff-Commander Tizard, R.N.), whilst investigating the nature of the Wyville-Thomson Ridge and the adjacent portions of the Faeröe Channel. All the forms, excepting these from Station 3, were obtained from deep water, and the collection, as a whole, is both rich and interesting. One species and two well-marked varieties have not hitherto been described, and two other species have only been found once previously. The series consequently forms a valuable supplement to the collections made during the cruises of H.M.S. "Porcupine" and the "Knight Errant," and is an important addition to our knowledge of the fauna of this region of the Atlantic. I propose to reserve any remarks upon the general character of the asterid fauna of the Faeröe Channel until treating of the collections obtained during the "Porcupine" and "Lightning" cruises.

I am indebted to Mr Murray for his kindness in placing this collection in my hands.

I. List of the Species Collected.

1. *Pteraster militaris* (O. F. Müller), Müller and Troschel.

   Station 2. August 5, 1882. Lat. 59° 37′ 30″ N., long. 6° 49′ W.
   Depth, 530 fathoms; bottom temperature, 46°·2 Fahr.

2. *Pteraster militaris*, var. *prolata*, nov. (Plate XXVI. fig. 1.)

   Station 9. August 23, 1882. Lat. 60° 5′ N., long. 6° 21′ W.
   Depth, 608 fathoms; bottom temperature, 30° Fahr.

This is a remarkable form, differing greatly in general appearance from the normal type of *P. militaris;* and although it accords in the main with the diagnostic formula of that species, the majority of the characters differ more or less in degree. It is not improbable that a series of examples might ultimately warrant its being ranked as a distinct species; but for the present I prefer to

place the solitary specimen as a variety of *P. militaris* until further material is available—a course which is sufficient to identify the form, and at the same time indicate the nearest specific affinities.

The variety is characterised by the following points:—The great length and narrowness of the rays; $R > 3r$; $R = 58$ to 60 mm., $r = 18$ mm.; breadth of a ray at the base, 18 to 22 mm. extreme measure. The dorsal paxillæ appear usually to have one of their spinelets much more robust than the two or three companion spinelets, which are remarkably fine and delicate, and the tips of the spinelets can scarcely be said to protrude through the supradorsal membrane, notwithstanding that this latter is placed rather loosely upon them, and much wrinkled. Two or three lineal series of paxillæ are more or less clearly distinguishable along the sides of the rays. On the actinal surface the segmental apertures are remarkably large, and the aperture-papillæ are much broader and more robust at their proximal portion than in *P. militaris*. In the ambulacral spines the three inner spines of each transverse comb form a line oblique to the furrow, the comb being curved aborally at the margin of the furrow, and the position of these spines upon the adambulacral plate being also oblique in relation to the plane of the ray. The actino-lateral spines are very short, and the outer portion of the web which proceeds from the outermost ambulacral spine, *i.e.*, the membranous continuation of the transverse comb upon the actinal membrane, is much more prominent than in the typical form of the species, and extends up to the margin of the lateral fringe. Although these differences may appear insignificant verbally, they produce when combined a striking facies, the characters of which can hardly be explained, as being simply the modifications of the normal form consequent on the conditions of a deep water habitat, since the example of *P. militaris* from 530 fathoms (Station 2), recorded above, differs in no way from the normal form.

3. *Archaster tenuispinus* (Düben and Koren), Sars.

Station 9. August 23, 1882. Lat. 60° 5′ N., long. 6° 21′ W.
Depth, 608 fathoms; bottom temperature, 30° Fahr.

4. *Archaster bifrons*, Wyville Thomson.

Station 10. August 24, 1882. Lat. 59° 40′ N., long. 7° 21′ W.
Depth, 516 fathoms; bottom temperature, 46° Fahr.
Station 11. August 28, 1882. Lat. 59° 29′ N., long. 7° 13′ W.
Depth, 555 fathoms; bottom temperature, 45°·5 Fahr.

5. *Astropecten Andromeda*, Müller and Troschel.

Station 10. August 24, 1882. Lat. 59° 40′ N., long. 7° 21′ W.
Depth, 516 fathoms; bottom temperature, 46° Fahr.

Station 11. August 28, 1882. Lat. 59° 29′ N., long. 7° 13′ W.
Depth, 555 fathoms; bottom temperature, 45°·5 Fahr.

The propriety of retaining this form in the genus *Astropecten* appears to be questionable. I propose to reserve the discussion of the subject until dealing with some allied forms obtained by the "Challenger" expedition.

6. *Luidia ciliaris*, Philippi.

Station 3. August 8, 1882. Lat. 69° 39′ 30″ N., long. 90° 6′ W.
Depth, 87 fathoms; bottom temperature, 49°·5 Fahr.

I consider this form separate from *L. Sarsii*, D. and K. Both species were comprised in Forbes' *L. fragilissima*. I regard *L. Sarignyi*, Audouin, distinct from either.

Rhegaster, gen. nov.

Marginal contour subpentagonal; rays slightly produced. Abactinal surface more or less convex, actinal flat. The whole body covered with membrane, beset with crowded spinelets.

Abactinal skeleton composed of irregular plates, crowded and subimbricated in places, which leave small irregularly disposed meshes. The whole skeleton is hidden in a thick membrane, and furnished with a compact covering of small, uniform, crowded spinelets. Papulæ small, numerous, isolated, irregularly distributed over the whole area. Infero-marginal plates large, forming the margin of the test. Supero-marginal plates superficially invisible, concealed in the dorsal membrane. Actinal interradial areas with large subregular plates, hidden by a superficial membrane, with small crowded spinelets.

Adambulacral plates broader than long. Ambulacral spines short and thickly invested with membrane, forming a regular furrow-series and several subregular longitudinal rows externally. Ambulacral sucker-feet in simple pairs, with small sucker-disk.

Madreporiform body small, midway between margin and apex. Anus subcentral. No pedicellariæ.

This genus comes within the scope of the family *Asterinidæ* as defined by Dr Viguier, and appears to be well distinguished from the other genera of the group. In addition to the species now described, I include in the genus the interesting form named by Dr Stuxberg* *Solaster tumidus*, but which has more recently been referred to the genus *Asterina* by Drs Danielssen and Koren.† The latter naturalists have given an admirable description, and two detail

* *Öfversigt af Kongl. Vet.-Akad. Förhandl.*, Årg. 35, 1878 (1879), No. 3, p. 31, pl. vi.

† *Nyt Mag. f. Naturvidensk.*, Bd. xxvi. hft. 2, p. 182, pls. i. and ii. figs. 6–10.

figures of specimens dredged during the Norwegian North Atlantic Expedition, and a well-marked variety (var. *tuberculata*, D. and K.) is also defined. DANIELSSEN and KOREN state that they place the *S. tumidus* provisionally as an *Asterina*, and mention at the same time a number of important points wherein the form differs from that genus. The determination appears to have been published with cautious hesitation, and I feel bound to express regret that the circumstance of the discovery of the new species should force upon me the undesired course of forestalling the Norwegian savants in the establishment of a genus for the reception of a form upon which they have bestowed such careful study.

Through the kindness of Professor LOVÉN, I had the privilege of examining Dr STUXBERG's type specimens when in Stockholm last autumn, and I am able to confirm the opinion of Drs DANIELSSEN and KOREN in regarding the original reference of the form to *Solaster* as altogether untenable.

7. *Rhegaster Murrayi*, n. sp. (Plate XXVI. figs. 2–7.)

Station 5. August 10, 1882. Lat. 60° 11′ to 60° 20′ N., long. 8° 15′ to 8° 8′ W.

Depth, 433 to 285 fathoms; bottom temperature, 43°·5 to 40°·8 Fahr.

Marginal contour subpentagonal, rays slightly produced; the lesser radius in the proportion of 77 per cent., or as 5 : 6·5. R = 14·3 mm., r = 11 mm.

Interbrachial angles somewhat indented at the median interradial line, from whence the contour curves outward faintly, consequent on a slightly tumid swelling at the base of the ray, and is then gracefully incurved towards the tip, which is obtuse and rounded. Abactinal area high and convex over the disk, sloping down regularly to the extremity of the rays, the height at the centre of the disk being 11·75 mm. A feeble sulcus or depression is present on the outer part of the median interradial line, which emphasises the tumid character of the base of the rays. Actinal surface more or less flat, excepting that the rays are slightly turned up at their extremity, and that a rather sharp depression occurs in the interbrachial areas along the inner part of the median interradial line, behind the mouth-plates.

Dorsal area covered with short, delicate spinelets, all of uniform length and size, their lower portion being apparently sunken in membrane. The spinelets stand perpendicular and are closely placed, presenting to the naked eye the appearance of a fine and uniformly granular surface. When magnified the spines are seen to be slightly expanded or flaring outwardly, and to be composed of many rods or lamellæ, with the extremity of each individual lamella terminating in a short thorn-like point.

The spinous dorsal area is punctured with numerous small but conspicuous pores, which are irregularly distributed at small but unequal distances apart over the whole area, excepting the extremities of the rays and a narrow band along the median interradial line; towards the margin the apertures are smaller, wider apart, and less frequent. Through these apertures the papulæ are protruded, and under magnification a small but definite circlet of the dorsal membrane surrounding the puncture of the papula, and unencroached upon by spinelets, may be seen. No grouping of the dorsal spinelets occurs, which in any way indicates the outlines of the underlying plates of the abactinal floor; and the only break in this perfectly uniform covering consists of a number of most minute channel-lines, which run irregularly here and there amongst the spinelets, the only one of these maintained with any regularity being a long straight channel, similar in breadth to all the others, extending along the median interradial line. The anal aperture is subcentral and distinct, and is surrounded by slightly larger spinelets. The madreporiform body is very small, round, and with numerous striæ. It is situated rather nearer to the margin than midway to the centre of the disk, and the surrounding portion of the test is slightly prominent.

Actinal interradial areas extensive, and with their outer margin conspicuously festooned by the infero-marginal plates. Infero-marginal plates eight to nine in number from the interbrachial line to the tip of the ray; the contour of their outer margin is rounded, and bears a group of eight to twelve spinelets, rather larger and more robust than those of the dorsal area above described. The plates are entirely covered with spinelets—the part which falls in the side of the ray with spinelets similar to those on the dorsal area, and the ventral portion with spines similar to those on the ventral area. When the starfish is viewed in profile, the marginal plates are seen to be clearly marked out by vertical furrows as well as by their prominent tumidity; but the junction of the infero-marginal with the supero-marginal plates, or indeed the presence of these latter at all, is indiscernible to superficial observation. Seen on the actinal side, the marginal plates are clearly defined by well-marked channels or furrows, and these run in oblique lines from the margin up to the adambulacral plates. The furrows are almost regularly parallel, hence the areas or columns they define are of nearly uniform breadth throughout. Consequent on their diagonal direction, a triangular space occurs in the median interbrachial line in the inner portion of the area, which is not conformable to the arrangement above described, the channels which traverse it converging towards the apex of the triangular space, a short distance removed from the margin of the disk. The whole ventral area is covered with small, almost spicular, spinelets, which are short, sharply pointed, and with their bases buried in membrane. The spinelets are all nearly uniform

in size, rather widely spaced, and are directed outward, almost horizontally, the angle at which they stand to the actinal surface being very small.

Ambulacral furrows narrow and almost uniform in breadth throughout. Adambulacral plates broader than long, bearing from five to eight spines. The ambulacral spines form a regular inner or furrow series, which arches over and almost conceals the ambulacral sucker-feet, and three sub-regular outer rows more or less clearly defined. The following is the arrangement of the spinelets on the plates:—Of the inner or furrow series there are two on each plate, which stand side by side and slightly oblique, especially towards the end of the ray. These two spines are regular throughout the ray, and are of equal size, short, compressed, lanceolate, tapering to a sharp point, and invested in membrane, which adds to the apparent breadth of their base. The outer spines are subject to a considerable amount of variation, both in number and position. Three only may be present, each placed behind the other, external to the furrow spines, forming a transverse series on the adambulacral plate, or one, two, or even all three of these spines may be reduplified—the companion spine usually standing rather oblique. These variations do not appear to be dependent on position in the ray, but may occur in any part. All the outer spines are of uniform size, cylindro-conical in shape, rather obtusely pointed, and covered with membrane.

Mouth-plates form a triangular mouth-angle, not prominent or protuberant superficially, and perfectly conformable with the triangular outline of the interradial area. The mouth-aperture is completely closed, and the arrangement of the armature of the mouth-plate is suggestive of that in certain *Goniasteridæ*. The mouth-spines are short, robust, and stand perpendicular. One odd spine is placed at the extreme angle, at the junction of the two plates of a mouth-angle, and five similar spines, all closely placed, occupy the free or furrow margin of the plate, decreasing in size as they recede from the mouth; the odd spine being the largest, the next three slightly smaller, and the two outer ones much smaller. All the spines are cylindrical, slightly taper, and obtusely rounded at the tip. Upon the surface of the plates, and on a line with the two small outer mouth-spines, stand two short secondary or superficial mouth-spines, one on each plate, very robust at the base, conical and pointed; and, further outward again, a second, but much smaller, spine behind each of the secondary mouth-spines; this small pair perhaps belonging to the adambulacral plate adjacent to the mouth-plates. A single minute spinelet, situate on the median or sutural line of the mouth-plates, stands midway between each of the pairs of secondary mouth-spines; and no other spines of any description are present on the mouth-plates.

Remarks.—The form above described is nearly allied to *Rhegaster tumidus* (Stuxberg, sp.). The following appear to be the chief points of difference:—

The length of the ray is much less in the new species, the radial proportions being for *R. Murrayi*, R=1·3 *r*, and for *R. tumidus* R=1·9 *r*, in specimens of the same size. The rays are consequently much less defined, and are more widely expanded at the base. In *R. Murrayi* the marginal contour is distinctly festooned by the infero-marginal plates, and each of these bears a group of enlarged spinelets, neither of the characters being present in *R. tumidus*. The ambulacral spines appear to be more numerous in the new form, the armature of the mouth-plates somewhat different, the distribution of papulæ more numerous on the dorsal surface, and the character of the spinelets, both on the abactinal and actinal areas, more simple.

I have great pleasure in associating this interesting species with the name of Mr JOHN MURRAY, whose zealous labours in connection with deep-sea dredging are well known.

8. *Mimaster Tizardi*, Sladen.

Station 10. August 24, 1882. Lat. 59° 40′ N., long. 7° 21′ W. Depth, 516 fathoms; bottom temperature, 46° Fahr.

Station 11. August 28, 1882. Lat. 59° 29′ N., long. 7° 13′ W. Depth, 555 fathoms; bottom temperature, 45°·5 Fahr.

9. *Hippasteria plana* (Linck), Gray.

Station 3. August 8, 1882. Lat. 60° 39′ 30″ N., long. 9° 6′ W. Depth, 87 fathoms; bottom temperature, 49°·5 Fahr.

10. *Cribrella oculata* (Linck), Forbes. (Plate XXVI. fig. 8.)

Station 1. August 4, 1882. Lat. 59° 51′ 30″ N., long. 6° 21′ W. Depth, 240 fathoms; bottom temperature, 47°·6 Fahr.

Station 10. August 24, 1882. Lat. 59° 40′ N., long. 7° 21′ W. Depth, 516 fathoms; bottom temperature, 46° Fahr.

Station 11. August 28, 1882. Lat. 59° 29′ N., long. 7° 13′ W. Depth, 555 fathoms; bottom temperature, 45°·5 Fahr.

The specimens from Stations 10 and 11 have an abnormal appearance, even for this variable species, probably consequent on their deep-water habitat. The variation is characterised by the comparative smallness of the disk and the greater length and narrowness of the rays, which are subcylindrical and almost uniform in breadth throughout, especially in the small examples where the expansion at the base is very slight. The single example from Station 11 measures R=39 mm., *r*=5 mm., breadth of ray at the base 5·75 mm. The spinelets of the abactinal area are very small, and rather more widely spaced than in the normal form. They are conically pointed, and have the appearance

of being rooted in membrane and rather thickly invested at their base, which gives the spine-groups a larger and somewhat more expanded character than usual in shallow water specimens. The three examples from Station 10 are much smaller, and their spinulation is very minute and scanty, seldom more than two to four spinelets being present in a group. The effect of this is perhaps most striking in the armature of the adambulacral plates, where the group of spines external to the furrow-series becomes abnormally small and insignificant. The comparative length of the ray and its almost uniform breadth is very conspicuous in comparison with small specimens of similar size of the ordinary form, in which the ray is proportionally shorter in the young stage than in the adult. The colour in alcohol of the specimens under notice is a dirty greyish-brown.

Considering the known variability of the species, I do not at present feel justified in doing more than placing on record the character of the variation above noted. If a larger supply of material should ultimately necessitate the nominal recognition of this form as a deep-sea variety, it might appropriately be called *cylindrella*.

11. *Zoroaster fulgens*, Wyville Thomson. (Plate XXVI. figs. 9–11.)

(*Zoroaster fulgens*, Wyv. Thoms. (1873), *The Depths of the Sea*, p. 154, fig. 26.)

Station 11. August 28, 1882. Lat. 59° 29′ N., long. 7° 13′ W.
Depth, 555 fathoms; bottom temperature, 45°·5 Fahr. A young example.

Station 13. August 31, 1882. Lat. 59° 51′ 2″ N., long. 8° 18′ W.
Depth, 570 fathoms; bottom temperature, 45°·7 Fahr.

A brief description and a woodcut of this handsome starfish were given by Sir Wyville Thomson in the work cited above. As no detailed description of the species has yet been published, the following may not be unacceptable :—

Rays five. R=125 to 130 mm.; r=14 to 15 mm.

Rays very long, narrow, subcylindrical, and tapering throughout to a finely pointed extremity; arched on the abactinal surface, and tumid on the actinal surface on either side of the furrow, which is deeply sunken. Interbrachial angles acute. Breadth of a ray at the base 17 mm.

The disk is rather higher than the rays and slightly tumid. The calcareous skeleton of the whole test is formed of suboval or subhexagonal plates, disposed in perfectly regular longitudinal and transverse series. The following is the arrangement they present. Surrounding a dorso-central and five small radially placed plates are five large plates interradial in position; and outside and alternating with these are five similar but rather smaller radially placed plates.*

* It will be noted that these plates represent in a remarkable manner the dorso-central, the under basals, the basals, and the radials respectively of the crinoid calyx.

Outward from each of the radial plates proceeds a longitudinal series of plates which extends along the median dorsal line of the ray, each plate regular in form (subhexagonal) and touching or slightly imbricating upon its next serial companion. On either side of this median line of plates is a parallel line of smaller plates, and these are succeeded by a line or series of plates nearly equal in size to those of the median line; the outer of these lines of plates standing on the rounding which separates the dorsal and lateral areas of the ray. Between this dorso-lateral line and the adambulacral plates are five longitudinal and parallel series of plates, the three upper rows forming the sides of the ray and the two lower being on the tumid actinal surface. The plates of the two upper rows of the lateral series are broader than those in the three lower series. The longitudinal arrangement of all the series is perfectly regular, and the plates diminish gradually in size as they proceed outward. Excepting the median dorsal line, the plates of all the other rows form regular transverse series, as well as longitudinal. The plates of the median dorsal line are slightly larger than the others, and consequently do not correspond. All the plates are contiguous, but leave a small diamond-shaped or sub-circular mesh between the rounded corners of adjoining plates. This is covered with membrane, through which one or more small papulæ proceed, and on which are usually borne one, or occasionally two, small forficiform pedicellariæ. The meshes form perfectly regular longitudinal lines, and this character, as well as their presence, is rendered more conspicuous by the slightly tumid surface of the plates. The surface of all the plates is studded with a number of small, uniform, well-spaced miliary granules, on which are articulated very short ciliary spinelets thinly covered with membrane. The plates of the median dorsal line are sub-mammillated, rising to a small but definite tubercle in the middle, which gives attachment to a short, robust, conical spinelet, the surrounding portions of the plate being covered with the same small miliary granules and spinelets as the other plates. Isolated dorso-lateral plates are occasionally similarly mammilated and spined, and the large interradial plates on the disk are also usually thus furnished. On the plates of the three rows which succeed the adambulacral plates, there are usually one to three spinelets much longer and more robust than the accompanying miliary spinelets. These are naked, delicate, cylindrical, and taper to a fine extremity, and are generally arranged in slightly oblique lines, with the middle spine often more forward and longest when three are present, near the lower margin of the plate, and they are directed upward and appressed to the ray. The next row on the sides of the ray, *i.e.*, the fourth from the adambulacral plates, has one larger spine on each plate, of equal size to the afore-mentioned. The adambulacral plates are quite within the furrow, and are short but broad, extending far upward almost vertically. Each alternate plate is developed into a thin prominent ridge,

which extends far into the furrow and entirely separates neighbouring suckers, whilst the intermediate plates are smooth, and appear to form the true furrow-wall. Four ambulacral spines, which are moderately long, cylindrical, and slightly tapering, are placed in single file at intervals along the edge of the ridge, the innermost being usually the most delicate, and the outermost is usually the shortest. Two to five small forficiform pedicellariæ are attached by membrane to the extremity of the delicate innermost spine. One or two small ciliary spines may be present on the extreme outer edge of the adambulacral plate, adjacent to the first row of longitudinal plates; and two or three similar small spines are present in the same position at the outer edge of the non-prominent intermediate plates, but no spines whatever are present on the surface of these plates within the furrow.

The actinostome is deeply depressed, and the mouth-plates are entirely within the cavity, and are not apposable. They are armed only with pointed, moderately robust spines similar to the larger spines on the ridges of the adambulacral plates.

The madreporiform body is small and inconspicuous, and is placed external to one of the interradial plates.

The anal aperture is small, distinct, surrounded by a circlet of small ciliary spines, and is placed at the side of the dorso-central plate, and consequently slightly excentric in position.

The ambulacral sucker-feet form four rows. They are rather small, sub-conical, and terminated with a small but distinct fleshy sucker.

Premature Phase.—The young form, measuring R = 11 mm. and $r = 2{\cdot}25$ mm., has a very remarkable appearance, owing to the prominence and distinctness of the component plates of the skeleton. The disk is much higher than in the adult. The dorso-central plate is prominent, and assumes the shape of a rounded cone. The interradial and first radial plates are of nearly equal size, and are very tumid or almost semi-globular in form. The plates of the median dorsal line are large and distinct, occupying a large portion of the abactinal surface of the ray. The so-called dorso-lateral series of plates form the margin of the ray, and the intermediate plates are small. Between the "dorso-lateral" series and the adambulacral plates there are not more than two fully-developed longitudinal rows of plates, with a partially-developed series commencing to appear between the latter and the adambulacral plates. The terminal (ocular) plates are very large, somewhat resembling the shape of a serpent's head, and are armed with one or two pairs of comparatively large robust spinelets, near the extremity, which are directed outwards.

The large plates of the disk and the median dorsal line have already a small tubercle, but only some of these bear spinelets. All the plates have a few widely spaced and very minute granules and microscopic ciliary spinelets. The

spinelets on the lower rows of plates are comparatively long and well developed. The character of the alternate prominent adambulacral plates is already discernible, although not more than one or two ambulacral spinelets are present on each.

The madreporiform body is outside and external to the interradial plate, and almost in the ravine of the interbrachial angle. The anal aperture is excentral, and situated between the dorso-central plate and an interradial plate, standing in the right posterior interradius when the madreporiform body is placed in the right anterior interradius.

12. *Asterias Mülleri*, Sars.

Station 5. August 10, 1882. Lat. 60° 11′ to 60° 20′ N., long. 8° 15′ to 8° 8′ W.
Depth, 433 to 285 fathoms; bottom temperature, 43°·5 to 40°·8 Fahr.

II. Station-Lists.

The following lists show the species associated at the respective stations:—

Station 1. August 4, 1882. Lat. 59° 51′ 30″ N., long. 6° 21′ W.
Depth, 240 fathoms; bottom temperature, 47°·6 Fahr.
Cribrella oculata.

Station 2. August 5, 1882. Lat. 59° 37′ 30″ N., long. 6° 49′ W.
Depth, 530 fathoms; bottom temperature, 46°·2 Fahr.
Pteraster militaris.

Station 3. August 8, 1882. Lat. 60° 39′ 30″ N., long. 9° 6″ W.
Depth, 87 fathoms; bottom temperature, 49°·5′ Fahr.
Hippasteria plana.
Luidia ciliaris.

Station 5. August 10, 1882. Lat. 60° 11′ to 60° 20′ N., long. 8° 15′ to 8° 8′ W.
Depth, 433 to 285 fathoms; bottom temperature, 43°·5 to 40°·8 Fahr.
Rhegaster Murrayi.
Asterias Mülleri.

Station 9. August 23, 1882. Lat. 60° 5′ N., long. 6° 21′ W.
Depth, 608 fathoms; bottom temperature, 30° Fahr.
Pteraster militaris var. *prolata.*
Archaster tenuispinus.

Station 10. August 24, 1882. Lat. 59° 40′ N., long. 7° 21′ W.
Depth, 516 fathoms; bottom temperature, 46° Fahr.

Archaster bifrons.
Astropecten Andromeda.
Mimaster Tizardi.
Cribrella oculata var. *cylindrella.*

Station 11. August 28, 1882. Lat. 59° 29′ N., long. 7° 13′ W.
Depth, 555 fathoms; bottom temperature, 45°·5 Fahr.

Archaster bifrons.
Astropecten Andromeda.
Mimaster Tizardi.
Cribrella oculata var. *cylindrella.*
Zoroaster fulgens.

Station 13. August 31, 1882. Lat. 59° 51′ 2″ N., long. 8° 18′ W.
Depth, 570 fathoms; bottom temperature, 45°·7 Fahr.

Zoroaster fulgens.

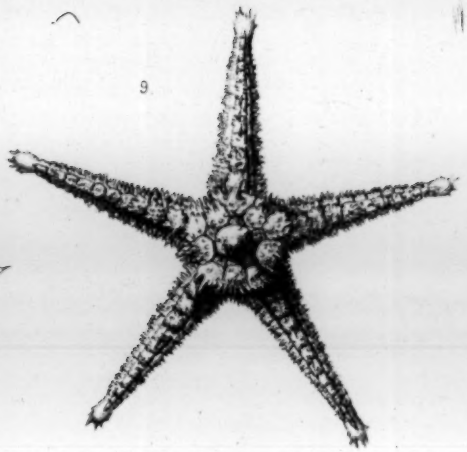
DESCRIPTION OF PLATE XXVI.

Fig. 1. *Pteraster militaris* var. *prolata.* Abactinal aspect; natural size.
Fig. 2. *Rhegaster Murrayi.* Abactinal aspect; magnified 2 diameters.
Fig. 3. „ Actinal aspect; magnified 2 diameters.
Fig. 4. „ Portion of the dorsal surface; magnified 20 diameters.
Fig. 5. „ One of the spines of the dorsal surface, seen in profile; highly magnified.
Fig. 5*a*. „ The same spine seen from above; highly magnified.
Fig. 6. „ Adambulacral plates and portion of the adjacent ventral surface; magnified 8 diameters.
Fig. 7. „ Mouth-plates; magnified 10 diameters.
Fig. 8. *Cribrella oculata* var. *cylindrella.* Abactinal aspect; natural size.
Fig. 9. *Zoroaster fulgens.* A young example. Abactinal aspect; magnified 3 diameters.
Fig. 10. „ Outline of the profile of the same specimen.
Fig. 11. „ Diagram of the plates of the disk, showing their correspondence with the crinoid calyx. The respective plates are marked as follows:—

1. Dorso-central.
2. Under Basals.
3. Basals.
4. Radials.

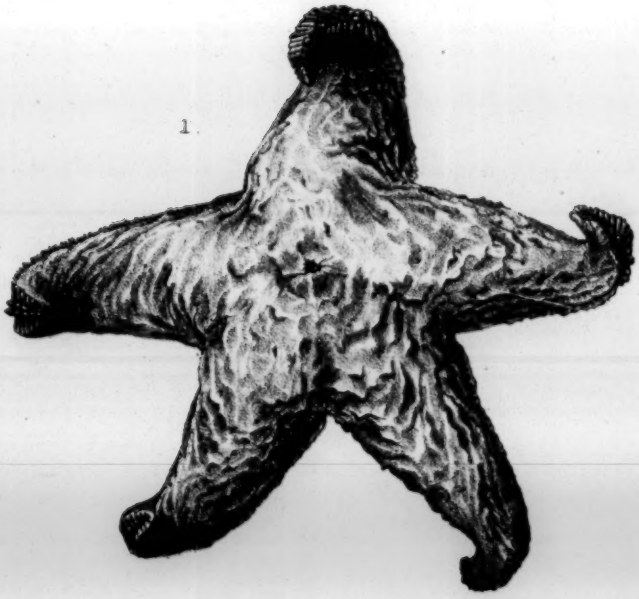


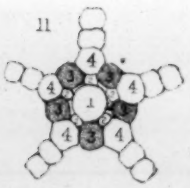


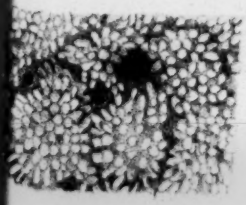




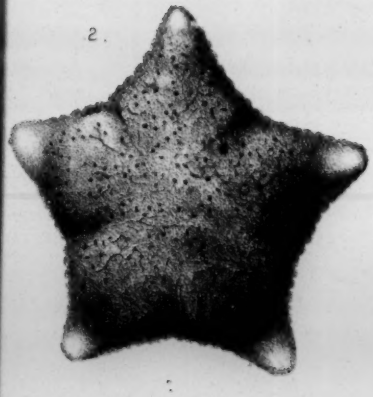




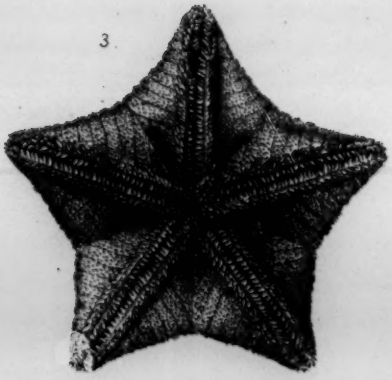












1. PTERASTER MILITARIS, var. PROLATA.

8. CRIBRELLA OCULATA, var. CYLINDRELLA.

2-7. RHEGASTER MURRAYI.

9-11. ZOROASTER FULGENS.

F.R.Michael &c.

A. Hutcheson & Son, Edin.

X.—*On a New Species of Pentastomum* (P. protelis), *from the Mesentery of* Proteles cristatus; *with an Account of its Anatomy.* By W. E. Hoyle, M.A. (Oxon.), M.R.C.S., Naturalist to the "Challenger" Commission. (Plates XXVII. and XXVIII.)

(Read June 4, 1883.)

For the parasites which form the subject of the present communication, I am indebted to my friend Professor Morrison Watson, who found them in a male specimen of *Proteles cristatus*, Sparrman, of whose myology he has since published an account.* Before entering upon a description of the entozoon, it may be allowable to say a word or two with respect to its host, which is not an animal of everyday occurrence. It was first described a little more than a century ago by Sparrman,† the Swedish traveller, as occurring in South Africa, where it is known to the farmers as the "grey jackal"; he gave it the name *Viverra cristata*. The only point in his description of any present interest is that its stomach "had nothing but ants in it, or to speak more properly, the white *termites*," which might be a valuable hint for any one who had the will and opportunity to investigate the life history of the parasite before us.

Since the time of Sparrman, it was erected into a separate genus by Geoffroy St Hilaire, and the name *Proteles* was chosen as expressing the fact that its anterior extremities were each provided with five, or the perfect number, of toes. It is now generally regarded as a type intermediate between the Hyænidæ and Viverridæ, its appearance when alive being strikingly like that of small hyæna.‡

The animal dissected by Professor Watson remained some days before the abdomen was opened, a circumstance which affected very prejudicially the histological preservation of its inhabitants, and made me hesitate for some time as to whether it would be worth while to attempt a complete account of the creature's anatomy; however, in consideration of the rarity of the specimens, it was resolved to make the effort, and the result has been the discovery of some interesting anatomical relations, although the account of the minute structure is in many particulars less complete than it would otherwise have been.

* *Proc. Zool. Soc. Lond.*, p. 579, 1882.

† Sparrman, Andrew, M.D., *A Voyage to the Cape of Good Hope, &c.* Translated from the Swedish original, London, 1786, vol. ii. p. 177.

‡ Flower, *Proc. Zool. Soc. Lond.*, p. 474, 1869.

The Enclosing Cyst.

The parasites, to the number of about ten, were enclosed in cysts in the mesentery, and their appearance is shown in the accompanying woodcut (fig. 1). Each is coiled into a more or less complete circle, and, in every case examined except one, the ventral surface formed the convexity of the curve.



Fig. 1. General appearance of the encysted parasite.

The cyst itself presents nothing in its structure worthy of special note; it consists of closely interwoven fibrils of connective tissue, imbedded in a quite homogeneous matrix; the wall is about 0·05 mm. thick, and it is more compact towards the inner than the outer surface.

The External Appearance.

The form of the body is (Pl. XXVII. fig. 1), speaking generally, cylindrical in the anterior half, and slightly tapering in the posterior, until it ends in a blunt cone. In some specimens the last two segments presented an appearance which may be aptly described in the words used by Diesing in speaking of another species, "cute externâ in formâ præputii"; but this was by no means constant.

The head is hemispheroidal, and is followed by a smooth cylindrical portion, which is of very variable length; in some cases it scarcely seems to exist at all, whilst in others it measures from 2 to 3·5 mm. (*cf.* Pl. XXVII. fig. 1, and woodcut, fig. 2).



Fig. 2. Ventral surface of the head.

This is succeeded by a number of annuli, which give the body a decidedly vermiform appearance, although, as will be seen in the sequel, this segmentation is scarcely at all reproduced in the internal organisation.

The number of the annuli varies with the sex, and also, though to a less extent, with the individual; it amounts in the males to 16 or 17, in the females to from 18 to 22. Each of these rings is separated by a constricted portion of the body, which may conveniently be termed the "interannular space"; these are somewhat less than the annuli, not only when measured transversely to the creature, but also longitudinally, except when it is very fully extended, under which circumstances the two sets of rings become about equal. Furthermore, the interannular spaces are of much weaker consistency than the annuli, as will be explained in treating of the internal anatomy; and in correlation with this fact, it is to be noticed that when the animal is coiled up, it is the interannular spaces which give way to allow of this, the annuli scarcely undergoing any change at all in breadth, but approaching each other on the concave aspect of the curve.

On the ventral surface of the head, and about 1 mm. from its anterior

margin, in the middle line, can be readily seen, even with the naked eye, a circular or slightly oval mark; this is the line which indicates the boundary of the oral papilla (woodcut, fig. 2). On either side of it are two slits, about 0·5 mm. in length, whose anterior extremities converge towards the middle line; these are the orifices of depressions of the cuticle which contain the hooks, and the points of these may generally be seen, under a low magnifying power, protruding from them.

The orifices of the sexual glands are somewhat difficult to observe, but in many cases they can be made out by careful examination, after the spirit has been allowed to evaporate from the specimens. The male genital openings are two in number, and are situated about 1 mm. behind the mouth, close to the middle line, and one at either side of it (Pl. XXVII. fig. 1, *g.o*). The female genital apparatus opens also in the middle ventral line, but within less than 1 mm. of the posterior extremity. All three are perfectly simple orifices, without any prominence.

These were all the points worthy of note observed on the external surface. I could find no tactile papillæ, such as are to be seen in *Linguatula tænioides*, although I looked for them with great care.

The Body-Wall.

The wall of the body consists of three distinctly marked layers—

1. The Cuticle.
2. The Epidermis.
3. The Subepidermic Layer.

1. *The Cuticle* (Pl. XXVII. fig. 9, *cu*) is a thin even layer which covers the whole surface of the body, including the invaginations in which the hooks are situated, and sends inwards prolongations which line the œsophagus, the rectum, and the genital ducts. Its thickness is on the average about 0·01 mm., and presents no noteworthy changes in different parts of the body, except that it is slightly thinner in the invaginated portions.

There can be little doubt, from the analogy of different forms of life, that it is composed of chitin, although I attempted no investigation on this point, beyond ascertaining the fact that it did not dissolve in boiling solution of caustic potash. It is to all appearance quite structureless, even when examined under high powers of the microscope; no trace could be found of the pores mentioned by Leuckart in *L. tænioides*,* nor did the cuticle appear to be divided into two distinct layers, which was probably owing to the immaturity of the specimens.

* *Bau u. Entwick. d. Pentastomen*, Leipzig u. Heidelberg, 1860, p. 30.

The annuli, however, are perforated by large pores or "stigmata," arranged in from 6 to 8 irregular rows, but none of these are found in the interannular spaces.

These stigmata are about 0·014 mm. in diameter, and almost circular in form, and when seen *en face* present a double contour, which is due to the difference in density of the cuticle immediately surrounding the stigma; when seen in section they appear very slightly constricted, so as to approach an hour-glass in shape (Pl. XXVII. figs. 9 and 11); the cuticle immediately surrounding the stigma is more highly refractile, and therefore probably also of greater density than the other portions; but there is no clear line of demarcation between these as indicated by LEUCKART in *L. tænioides.** In some cases the portion of cuticle around the stigma is slightly thickened, although this is by no means constant.

A surface view of the cuticle shows, moreover, a number of small irregularly oval markings, arranged in fairly even rings around the pores, and producing an appearance which recalls that of a transverse section of bone with its Haversian canals and lacunæ (Pl. XXVII. fig. 2). These marks are due to the extremities of the epithelial cells, which form the next layer of the body-wall, as was very distinctly visible in one small portion of the cuticle which had this layer still attached to it.

While treating of the cuticle it will be well to describe the hooks which are modified portions of it. Their form is shown in the drawing (Pl. XXVII. figs. 3 and 12) better than it can be described in words; they are seen to be composed of two separate joints, moved by appropriate muscles, which will be treated of in the sequel. Their homology has been fully discussed by LEUCKART in his classic monograph, and my investigations have not enabled me to add anything to what he has written upon this head.

2. *The Epidermis,* which follows immediately upon the cuticle, is a single layer of columnar epithelial cells, 0·012 to 0·02 mm. in thickness (Pl. XXVII. fig. 9, *ep*). The cells contain a distinct nucleus, generally oval in form, and situated in varying positions in different cells; in some cases a nucleolus was visible.

3. *The Subepidermic Layer* (Pl. XXVII. fig. 9, *par*) composes the greater part of the body-wall of the animal. It varies greatly in thickness, but on an average may be taken at 0·2 mm., the extremes being about 0·1 mm. and 0·35 mm.; as a general rule, it is thinnest along the dorsal surface, and in the narrow ventral intermuscular space (see p. 169) it is not unfrequently absent altogether.

The cells of which it is made up are of very various sizes and shapes; occasionally their diameter nearly equals the length of the epithelial cells, but

* *Loc. cit.*, p. 31, Tab. i. figs. 7 and 8.

in most cases they are only almost one-third the size of these. They contain a finely granular protoplasm, and a small spheroidal, ovoid, or somewhat irregularly shaped nucleus. They are packed closely together, and occupy the whole space between the subcuticular epithelium and the longitudinal muscle bundles.

Among them are scattered the large glandular cells which will be described as part of the secretory apparatus (see p. 178); and they are traversed by many of the muscle-fibres, which will also be described in a special section of the paper.

Towards the body cavity this layer, or the longitudinal muscle-bundles where they interpose, is marked off in the sections by a clear definite line, which becomes deeply stained. This I take to be the cœlomic epithelium (endothelium), but unfortunately none of my specimens were sufficiently well-preserved to enable me to speak with confidence on this point.

The Muscular System.

When the animal is opened by a median dorsal incision, and the body-wall spread out and examined from within, an appearance is seen such as is shown in Pl. XXVII. fig. 17.

Longitudinal bands are crossed by transverse bands, and interspaces, roughly speaking, rectangular in form, are left between them. The ventral median line is marked by a series of square gaps, towards the margins of which are placed a number of radiating fibres. Along the lateral sides of the successive squares there stretch two broad bands (fig. 17, *m.l'*, *m.l'*), which are composed of longitudinal muscular fibres, and, though somewhat variable in their breadth, are nearly as wide as the squares. Beyond these, again, are a number (commonly 8–10) of very much narrower longitudinal bands (fig. 17, *m.l*).

A closer examination confirms the view that these longitudinal bands are composed of muscular fibres, but the case is otherwise with the transverse bands. These, as was pointed out by Leuckart,* are cellular in structure, and consist largely of the glandular cells which will be alluded to when treating of the subepidermic cell-layer (p. 178). They correspond with the external annulations of the animal, and on focussing deeply through these bands the stigmata are seen, whilst none are visible in the spaces between them.

The muscular system of this parasite cannot, however, be fully understood by means of such a preparation as has just been described; to render our knowledge complete, transverse sections are necessary; and, when the information derived from these is taken into account, there are seen to be present three systems of muscular fibres—

* Leuckart, *loc. cit.*, p. 39.

1. *Transverse fibres*, immediately underlying the epidermis.
2. *Longitudinal fibres*, arranged in bundles, lying for the most part immediately below the cœlomic epithelium.
3. *Oblique fibres*, placed obliquely, however, both to the dorso-ventral plane of the body and to planes cutting it transversely.

1. *The Transverse Layer* of muscular fibres is very thin, it being only one fibre thick; in some cases there seemed to be two or even three such layers, but this appearance was probably owing to a slight obliquity of those particular sections.

It is situated immediately within the epithelium, so that its fibres are for the most part parallel to the cuticle, and they lie in planes which are approximately transverse to the body of the animal.

The appearance of this sheet of fibres is seen in Pl. XXVII. fig. 14; the fibres branch dichotomously, and at intervals unite with each other so as to form a fine network with elongated meshes, in which the cells of the parenchyma of the body-wall may be noticed.

In the body proper of the animal this layer is developed almost exclusively on the sides, its fibres not often crossing the ventral, and hardly ever the dorsal median line.

In one specimen about 1 mm. from the caudal extremity, I noticed a small patch of these fibres dorsally situated, but this might have been an individual peculiarity. The cephalic region, however, shows a great change in the arrangement of this layer, for there it is best developed on the dorsal and ventral aspects of the body, and to a much smaller extent on the sides.

With respect to the nature of the individual fibres, but little can be said. They are very thin (about 0·001 mm.), and I could not detect in them that transverse striation which was noticed by LEUCKART.* Some of the better preserved specimens showed, however, a kind of sarcolemma, an exceedingly thin sheath with a well-defined outline, and with small ovoid nuclei (Pl. XXVII. fig. 16, *nu*).

2. *The Longitudinal Layer* varies a good deal in its arrangement in different parts of the animal, and it will be advantageous to describe it as seen at about the middle of the body. A section taken in this situation is shown in Pl. XXVII. figs. 10 and 13, *m.l*), and it will be at once noticed that the longitudinal muscles are situated at some distance from the external surface, being separated from it by the whole thickness of the body-wall. Its fibres, moreover, are grouped into definite bundles, which in the ventral region present a more or less elongated oval section, while in the lateral and dorsal regions they are

* *Loc. cit.*, p. 40.

more nearly circular. A space free from muscles passes down the middle line ventrally, and this space, as we shall see, extends throughout the whole length of the animal.

The bundles are thus arranged :—About four or five thin band-like portions are placed in the compartments formed by the splitting of the ventral margin of the oblique muscle-layer (fig. 10), and a somewhat thicker one lies on the inner surface of this layer close along its ventral margin. It is these bands which, overlapping each other by their outer margins, produce the appearance of a broad band, seen when the body-wall is examined from within (Pl. XXVII. fig. 17, *m.l'*).

Passing outwards there are next noticed smaller bands, of somewhat irregular figure in section, lying between the oblique muscles and the body-wall; and then, after passing the point where the former of these are inserted into the latter, we come to a number (8–12) of rounded bundles which stand out from the body-wall, and would lie free in the body-cavity were they not covered with a thin membrane (cœlomic epithelium ?).

In LEUCKART'S* description of these muscles in *P. proboscideum*, he mentions a space free from muscles extending down the dorsal median line of the animal similar to that above mentioned on the ventral aspect; this state of things certainly did not obtain in the species at present under consideration, the longitudinal bundles succeeded each other quite regularly across the dorsal surface, and there was no thinning out of the mesoderm towards the median line (Pl. XXVII. fig. 10). LEUCKART furthermore alludes to a division of each lateral muscle-mass into a dorsal and a ventral portion, but this also was not to be noticed in my specimens.

Towards the tail (Pl. XXVII. fig. 13) the muscular system gradually becomes less and less strongly developed, until at distances of less than 0·5 mm. clearly defined fibres are not to be found. The longitudinal and oblique systems appear to arise almost side by side, and the former is seen in sections a little less than 1 mm. from the hinder extremity to consist of about nine bundles on each side, which at this point show much less variety in size and shape than in other parts of the animal. Even here, however, there are a certain number of bundles, somewhat broader and more flattened, connected with the ventral margin of the oblique layer of fibres. The number of fibres in each bundle varies from about 10–30, but I could not make out satisfactorily any constant relation between the size of the bundles and their position.

The fibres of which the longitudinal muscles are composed are almost 0·008 mm. in diameter, usually oval in transverse section, except where they are rendered polygonal by mutual pressure. In most cases the inner portion of the fibre is pale in colour, and bordered by a fine deeply stained line

* *Loc. cit.*, p. 41.

(sarcolemma ?), in which is often seen an ovoid thickening which may be due to the presence of a nucleus. When they are well preserved these fibres show a clear transverse striation, the striæ being separated from each other by a distance somewhat greater than the diameter of the fibre; thus resembling those of the oblique fibres shown in Pl. XXVII. fig. 9.

3. *The Oblique System* of muscles does not form a complete layer encircling the body, but consists of two muscular planes, which take origin near the ventral median line, and pass upwards and outwards, diverging at an angle of sixty degrees or more (Pl. XXVII. fig. 10, *m.o*). Each plane appears in transverse section as a thin line, never thicker, and usually somewhat thinner, than a single fibre of the longitudinal muscles, but it shows a longitudinal striation as if composed of several fibrils. Near the ventral margin, and to some extent also near the dorsal, this lamella is seen to split into a varying number of thinner portions, between which are situated the longitudinal muscle-bundles as already described.

This muscular group, however, is oblique in two senses; as we have just seen, its fibres form two lamellæ inclined towards the median plane of the body, but in addition to this, they pass obliquely downwards and forwards from one segment of the body into the next, as is shown in Pl. XXVII. fig. 17. These fibres appear to be homologous with one half of the cruciform systems, which LEUCKART describes and figures in *P. proboscideum*,* but of the other half, those, namely, which proceed downwards and backwards, no trace was to be found.

If it be correct to assume that the crucial fibres are the remains of one or two complete coats of oblique fibres, if we suppose the process of degradation carried still further, then the fibres passing downwards and backwards, not being of so great utility in the movement of creeping as those passing in the other direction, would be the first to disappear, and these latter only would remain.

The fibrils of which this layer is composed are about 0·003 mm. in diameter, but they frequently exhibit a longitudinal striation, as though made up of still finer elements, and rarely the transverse striation was clearly exhibited (fig. 9, *m.o*). At intervals along the fibrils small darkly-stained nuclei are to be observed, but whether these belong to the sarcolemma or to the connective tissue, I was unable to discover.

With respect to the mode of termination of the fibrils I can say but little; it was often quite easy to follow them as far as the subcuticular epidermis, and in a few cases an appearance was presented such as is shown in Pl. XXVII. fig 16, giving decidedly the impression that they passed between the cells of this layer and are inserted directly into the cuticle. It would hardly be safe

* *Loc. cit.*, p. 41, Tab. i. fig. 10.

to assert that this was generally the case, without an examination of fresh specimens, but it receives corroboration from LEUCKART'S account of *P. proboscideum*. Some of these oblique fibres, on reaching the inner surface of this epithelium, turn and pass along it, thus assisting in the formation of the transverse muscular coat already described (fig. 16).

Before quitting the muscular system, three points require a brief consideration,—the modifications which it undergoes in the tail and in the head, and its disposition with respect to the cephalic hooks.

In the tail about the point at which the longitudinal fibres first became noticeable, the two lamellæ have a somewhat different disposition ; instead of being inclined to each other at a considerable angle, they are much more nearly parallel, but separating from each other to give place to the intestine, they again approach slightly as they are inserted into the body-wall dorsally (Pl. XXVII. fig. 13).

The second point may be dismissed in a very few words ; on approaching the anterior extremity of the body, the splitting of the layer of oblique fibres towards its ventral margin is much further carried out (Pl. XXVII. fig. 10, *m.o*), and the bundles of longitudinal muscle-fibres in relation with it are more numerous and larger, so that the ventral band of muscles is much more prominent. Concurrently with this change, but proceeding much more slowly, is a gradual diminution of the bundles of longitudinal fibres in the remaining portions of the body. As we reach points still more anterior in the animal (about on a level with the œsophagus) the ventral longitudinal bands undergo a similar diminution, until in the neighbourhood of the hooks the regular longitudinal muscle-coat is represented only by a few isolated fibres.

The oblique fibres, on the contrary, become more numerous, and are disposed more nearly parallel to the median plane of the body, until finally they come into relation with the hooks, and there become adapted to a special function, as will presently be seen.

The Muscles of the Hooks.—The muscles which act upon the hooks have been studied by means of almost complete series of sections, both longitudinal and transverse, and though the general result of this inquiry is to corroborate LEUCKART'S * account of the matter, there are one or two differences which require to be noticed.

Attached to the hook itself are four muscles, one to the dorsal and three to the ventral extremity of its base.

The Extensor unci (Pl. XXVII. fig. 12, *u.e*), as the first of the muscles above mentioned may conveniently be called, arises from the inner or ventral surface of the basal joint of the hook, and its fibres pass forwards and inwards,

* *Loc. cit.*, pp. 46, 47.

to be inserted pinnately into a tendon which is attached to the dorsal angle of the hook.

The *Flexor unci* (fig. 12, *u.f*) is inserted into the opposite angle of the hook, and arises, as LEUCKART has well described, from the basal joint of the hook, its fibres crossing those of the muscle last mentioned.

The *Flexor accessorius unci* (fig. 12, *u.f.a*) is a long thin band which appears to arise in the mesoblastic tissue of the body, and passes forwards approaching the flexor unci on its ventral aspect at a slight angle, and is inserted close beside it.

The *Retractor unci* (fig. 12, *u.r*) passes forwards and slightly towards the dorsal surface, and is inserted close to the two last. It acts to some extent as a flexor, but in conjunction with other muscles, more particularly the extensor, it produces that movement of retraction of the hook as a whole which LEUCKART has described as occurring in the living *Pentastomum*, but which unfortunately I have not had the opportunity of witnessing.

In addition to these four muscles are two attached to the extremity of the basal joint of the hook.

The *Protractor basis unci*, arises from the anterior surface of the head, and passes backwards to be inserted into the posterior extremity of the basal joint of the hook. It consists generally of more than one slender bundle, and its action can be readily inferred from an inspection of the drawing (fig. 12, *u.b.p*).

The *Adductor basis unci* (if it be allowed to use the word in the sense of drawing towards the ventral surface) is inserted along with the last named, but its fibres pass inwards from an origin near the ventral surface of the body cavity (fig. 12, *u.b.a*).

In addition to the definite muscular bundles above described, a set of fibres arises from the cuticle all round the invagination in which the hook is situated; these muscles, which may be termed "retractors of the cuticle," are obviously charged with the function of facilitating the egress of the point of the hook from its sac and increasing the extent of its protrusion.

THE DIGESTIVE TRACT.

This portion of the animal's anatomy consists only of four well-defined portions—

1. The Oral Papilla.
2. The Œsophagus.
3. The Stomach.
4. The Rectum.

1. *The Oral Papilla.*—In the description of the outside of the animal, mention has been made of a small circle lying between the two pairs of hooks.

This is the external opening of an annular groove, whose depth is generally about equal to the diameter of the circle, though it is sometimes a little deeper. The two sides of the groove are almost in contact, so that its breadth is quite infinitesimal.

From this it follows that the papilla, which is separated by the groove from the surrounding tissues, is a short cylinder, of about equal length and diameter. It is not quite regular in form, however, but the base is a little contracted from side to side, while the antero-external angle is sometimes a little rounded off (Pl. XXVII. fig. 8).

The cuticle which covers the free extremity of the papilla is not to be distinguished from that covering the remainder of the body, while that upon the sides of the groove is a little thicker, and absorbs the staining material (hæmatoxylin) more greedily, and is provided with a number of small spines (fig. 4).

The subcuticular epithelium of this organ presents no note worthy of modifications, but its muscles are rather complex, and indicate that it is an organ of considerable functional activity.

The papilla itself contains two (possibly three) sets of muscular fibres—the first traverses it almost parallel to the longitudinal axis of the body, slightly approaching the ventral surface as it passes backwards (Pl. XXVII. fig. 8); the second passes from its base towards the free extremity, bending slightly inwards as it proceeds. Some of the sections of the papilla seemed to show a thin marginal layer of fibres, divided transversely, which would of course constitute a sphincter, but these appearances were so uncertain, that I do not feel justified in doing more than merely alluding to them.

In addition to these, a clearly-defined retractor bundle runs obliquely forwards from the middle of the body into the papilla (Pl. XXVII. fig. 8), while all around it slender groups of fibres pass outwards, and are inserted into the cuticle.

From a consideration of the structures above described, it seems probable that this papilla can be protruded after the manner of a proboscis; the last named muscles being specially efficacious in assisting this action; the subsequent retraction also is amply provided for. Furthermore, the intra-papillary antero-posterio fibres will, by their contraction, increase the space behind the papilla, which the retraction and consequent swelling of this latter will again diminish, thus obviously aiding the operation of deglutition. A third function possible to this organ is that of a sucker, to secure the adhesion of the parasite to its host.

No structure of this kind would appear to exist in *L. tænioides*, whose mouth is merely "a widely gaping orifice" (eine grosse und klaffende Oeffnung),* followed by a funnel-shaped pharynx, along which the chitinous lining is continued as far as the stomach itself.

* Leuckart, *loc. cit.* p. 55.

2. *The Œsophagus* commences at the bottom of the groove posteriorly, and after a variously curved course, opens into the ventral surface of the stomach some distance behind its anterior extremity (Pl. XXVII. fig. 8, *œ*). Its course is at first obliquely upwards and backwards, and its transverse section is crescentic, the horns being directed ventrally (fig. 6, *r*); the dimensions of this crescent are 0·16 mm. across the horns, while the lumen of the passage is only 0·012 mm. in width. This portion of the œsophagus is lined with chitin prolonged from the external covering of the body; and its wall is composed of a mass of cells in which distinct muscular elements could not be made out.

The œsophagus then turns directly backwards to pass beneath the anterior nerve commissure (fig. 8, *a.n.c*), and at this point its structure undergoes a change; the cuticular lining after becoming gradually thinner, entirely disappears, and outside the cellular wall there lies a covering of muscular fibres arranged as a sphincter; while, in addition to all this, the section of the tube becomes irregularly elliptical instead of crescentic, the transverse and dorso-ventral diameters being 0·1 mm. and 0·012 mm. respectively.

When the œsophagus has passed through the nerve collar, its direction tends more upwards, and very slightly forwards, and its lumen assumes an irregularly stellate form, owing, probably, to the contraction of the sphincter muscles, and consequent puckering of the cellular lining (fig. 6, *l*). It now turns backwards, and at the same time comes to lie in a mass of cells situated immediately below the intestine. The elements composing this mass are for the most part of ovoid form, the greatest diameter averaging 0·016 mm.; they have a finely granular content, and a large deeply-stained spheroidal nucleus, with a nucleolus. Their function must remain to a large extent the subject of conjecture; their histological characters and situation would suggest that they form a gland, but none of the sections examined have revealed any trace of duct or of excretory openings in the œsophageal wall.

After a short course through this gland-like organ, it turns directly upwards, and opens upon a small elevation in the floor of the intestine, at a point about 1 mm. behind its anterior extremity (Pl. XXVII. fig. 8).

3. *The Stomach* (Chylusmagen of Leuckart) needs only a few words of description. As stated above, it presents anteriorly a rounded cœcal extremity about 0·5 mm. in length, behind which is the opening of the œsophagus (Pl. XXVII. fig. 8). Its form is, speaking roughly, cylindrical, slightly tapering, however, as it passes backwards, and it lies evenly in the middle of the body cavity; its greatest diameter being about 0·75 mm. A little less than 1 mm. from the posterior extremity of the body the stomach terminates by opening into the rectum.

Of all the organs of the body the digestive tract was, unfortunately, the worst preserved, so that I am unable to give information of any great value as

to its histology. It is lined by a single layer of nucleated epithelial cells, and the remainder of the wall is made up of two indistinctly cellular layers, in which I failed to distinguish any definite muscular elements (figs. 5 and 10).

The wall thus composed is about 0·042 mm. in thickness near the head, but it commonly increases to about double this, and is much more compactly constituted in the more posterior portions of the body.

Two mesenteries (fig. 5) support this portion of the alimentary canal; these are not diametrically opposite to each other, but are separated by an angle of 90° to 120°. They are thin lamellæ (0·021 mm. thick), made up either of small rounded cells, or else of fibres placed longitudinally; on an average, two of these make up the thickness of the lamina. The mesenteries commence as continuous membranes about one and a half millimetres from the hinder extremity of the body, although traces of them are visible in transverse sections posteriorly to this.

In addition to the stomach, they support the hook-glands (Pl. XXVII. fig. 10), and in the anterior portion of the body the *vasa deferentia* come into relation with them, as will be more fully explained when speaking of those organs.

There would appear to be in *L. tænioides* nothing homologous to the structure just described, unless it is to be found in a number of distinctly muscular fibres which arise from the stomach, and spreading out in the form of a fan, unite with the muscular wall of the body;* but the differences between these two sets of structures are so many, that it would scarcely be justifiable to regard them as homologous, save as the result of an embryological inquiry.

4. *The Rectum* (Pl. XXVII. fig. 7) is about 0·75 mm. in length; in section it is compressed dorso-ventrally, its transverse diameter being 0·17 mm., while its upper and lower surfaces are almost in contact; it is lined with cuticle, 0·015 mm. in thickness, prolonged from the external surface of the body, below which is a layer of cells, forming part of the chitinogenous layer. Muscular elements seem to be entirely absent.

Secretory Organs.

Three distinct sets of organs must, in the present state of our knowledge, be grouped together under this head, although they differ widely in structure and probably in function also.

They are—

1. The Hook-Glands.
2. The Parietal Cells.
3. The Stigmatic Cells.

1. *The Hook-glands* (Hakendrüsen, Leuckart) are undoubtedly the same

* *Loc. cit.*, p. 59.

structures as VAN BENEDEN described in his *P. Diesingii*,* and as those to which LEUCKART alludes in *P. cylindricum*, *P. oxycephalum*, &c.† They are elongated bolster-shaped bodies, tapering slightly towards either end and flattened on the median surface which is in relation with the intestine (Pl. XXVII. fig. 10, *h.g*). They extend forwards into the head, but about the point where the œsophagus opens into it they leave the intestine, and passing outwards unite with the body-wall; posteriorly they extend to within a few millimetres of the hinder extremity of the body.

Their length is thus very little less than that of the entire animal, while their average diameter is about 0·7 mm., so that they fill up the greater part of the body-cavity on either side of the intestine.

Each gland is covered by a delicate membrane, and within is made up of very large cells varying 0·07 mm. to 0·15 mm. in diameter, of very diversified shapes and packed closely together.

The cells were found to contain a coarsely granular protoplasm, and a large nucleus (0·02 mm. in diameter) in which a nucleolus could only very rarely be distinguished.

In the centre of the gland may be seen the duct (fig. 10, *h.g'*), a tube 0·02 mm. in diameter, with a lumen of 0·008 mm., lined with a very delicate layer of chitin. This duct was traced forwards through a series of transverse sections nearly as far as the bases of the hooks; beyond this point, however, it could not be followed; but there can be no reasonable doubt that it opens in the invagination of the cuticle in which the hook is situated, as described by LEUCKART. I could detect no ducts passing towards the mouth, but only the two pairs proceeding in the direction of the hooks; neither the duct nor any portion of the gland passes through the nerve ring, as in *P. oxycephalum*.‡

These glands would seem from their position and relations to be homologous with the salivary glands of other Arthropoda; the fact of their opening at the base of the appendages and not into the cavity of the mouth might be an obstacle to the adoption of this view, unless perhaps these are to be regarded as homologous with the jaws rather than with the limbs of allied forms.

2. *The Parietal Cells* (Pl. XXVII. fig. 9, *p.c*) I propose for the present to term a number of large oval cells scattered in the mesoderm of the body-wall, because at present no opinion can be offered as to their function. They constitute one of the most conspicuous characters seen in the examination of sections, both longitudinal and transverse.

In form they are ovoid, generally flattened by mutual contact, and averaging 0·03 mm. in diameter; they contain a deeply stained spheroidal nucleus of

* *Ann. d. Sci. Nat.*, sér. 3, t. xi. p. 324, 1849.
† LEUCKART, *loc. cit.*, p. 67.
‡ *Loc. cit.*, p. 67.

about 0·008 mm. in diameter, within which a small nucleolus is generally to be seen; the protoplasm is finely granular and faintly stained.

These cells are arranged in groups of 2–5, and very commonly at the point where several cells meet may be observed an oval speck, from which fine radiating lines branch out (figs. 9 and 15). The similarity between this appearance and that depicted in some of LEUCKART'S figures will be at once apparent.*

The distribution of these cell-groups next demands attention; they lie among the smaller mesodermic cells constituting the body-wall, about midway between its inner and outer surfaces, and are disposed in zones, corresponding with the annuli of the body, and consequently with the stigmata, none being found in the interannular spaces. It is, in fact, the presence of these cells which causes the swelling of the annular regions of the body and the greater stiffness of the wall in those parts, which has been already alluded to.

In the annuli, however, these cell-groups are very closely placed, and in a transverse section they seem to form an almost continuous zone; more than fifty can often be seen in a single circumference.

The homology of these cells next demands our attention. Their position would seem to show that they correspond to those cells of *L. tænioides* which LEUCKART has called the hook-gland (Hakendrüsen, see Tab. i. fig. 11 of his monograph), and this view is strikingly confirmed by a study of their appearance (*cf.* fig. 15 with Tab. i. fig. 17). The form of the cells is the same, as also their arrangement in acini composed of 2–5; the radiating apparatus also, which LEUCKART regards as the commencement of the excretory apparatus, is the same in both. But if we admit this hypothesis we are placed on the horns of a dilemma, for we have in the creature before us a structure which is homologous with the hook-gland of *L. tænioides*, and another organ which is beyond all question the homologue of a gland which LEUCKART finds in *P. proboscideum* and other species, and which VAN BENEDEN has described in his *L. Diesingii*, and which, again, is declared to be the homologue of the hook-gland of *L. tænioides*.† Thus we have two separate organs both corresponding to the same organ. It appears to me that at present the only course open to us is to assume that we have here a condition in which there is a double set of organs, one of which is lost in certain forms, while the other disappears in others. This does not seem satisfactory, however, because both structures appear to be very well developed, and have by no means the aspect of rudimentary structures.

In the face of this difficulty, I regret the more that I was unable to trace the course of the excretory apparatus of these peripheral gland cells, even after the most careful scrutiny of the sections. This knowledge might have solved the mystery, but at present it must be left until some future occasion may furnish a supply of better preserved material.

* *Loc. cit.*, Tab. i. fig. 17.

† *Loc. cit.*, p. 67.

With regard to the function of this cell-system, I have, as will be inferred from what has just been stated, no theory to offer; if it be really a portion of the hook-gland, then the suggestions of LEUCKART seem the most apt that can be offered, and if not, the discovery of the destination of the secretion must precede any further hypothesis.

3. *The Stigmatic Cell-groups* (Pl. XXVII. figs. 9 and 11, *s.c*) have been already alluded to as situated immediately within the stigmata. They are spheroidal in form, and their inner surface projects only a little beyond that of the subcuticular epithelium, so that they have an average diameter of about 0·02 mm. They are not very transparent, and take up the straining material eagerly, so that their structure is somewhat difficult to make out. Each consists of from six to nine small cells, with clear or clouded protoplasmic contents, and a comparatively large variously-shaped nucleus. The outer aspect is moulded into a kind of short neck which lies within the stigma, and is closed by a fine very darkly stained line.

Such being the appearance of these structures, it becomes necessary to inquire into their homology and function. In LEUCKART'S classic* work there are described in the earlier developmental stages of *L. tænioides* vesicles of clear fluid in relation with the stigmata, and these in the adult are replaced by large cellular processes which project into the body-cavity. It would seem, then, that we have in the subject of the present investigation a condition intermediate between the two just described, and this is rendered more probable inasmuch as LEUCKART speaks of and figures an incipient segmentation.

These cell-groups are possibly homologous with the subcuticular glands described by KÖLLIKER in certain insects;† it is scarcely possible that they have any relation other than a merely analogical one with glands, which they closely resemble in structure, described by ANDREAE in *Sipunculus nudus*.‡

With respect to the function discharged by these structures it seems quite possible that they take part in the formation of the cyst which encloses the animals, unless they be excretory in nature, and destined only to come into full activity on the further development of the animal; it is not impossible, however, that both these suggestions may be true.

THE NERVOUS SYSTEM.

As might have been anticipated, the nervous system of the subject of this paper shows but slight differences from that of any similar forms which have hitherto been examined. It consists of a single median ganglion, showing, however, traces of a primitive division into two lateral halves, and of about

* *Loc. cit.*, p. 33.

† *Verhandl. d. phys. med. Vereins Würzburg*, p. 76, 1857.

‡ *Zeitschr. f. wiss. Zool.*, Bd. xxxvi. p. 201, Taf. xii., figs. 1 and 4, 1881.

equal length and breadth (0·28 mm.), while its thickness amounts to about 0·14 mm. A general view of its form and position, with the branches given out from it, is given in the dissection depicted in Pl. XXVIII. fig. 16, *n.g.* The two larger branches, which pass backwards, can be traced for more than half the length of the animal; they lie in the main parallel to each other, one on either side of the ventral median line. From either side of the large ganglion a branch passes along the œsophagus, and probably reaches the oral papilla.

In connection with the structure described by LIÉNARD * in several other Arthropods (*Spirocyclistus*, *Cossus*), it is interesting to note that the præœsophageal commissure in my specimens was double, and from the anterior cord two branches proceeded forwards.

The minute structure of the nervous system was so ill-preserved that no observations of value could be made upon it.

THE GENERATIVE ORGANS.

Both male and female specimens were fortunately present among those I had for examination, but while the genital apparatus of the former presented some noteworthy arrangements, that of the latter was not specially remarkable.

The Male Organs.

These may conveniently be described under the following heads :—

1. The Testis.
2. The Vesicula seminalis.
3. The Vas deferens.
4. The Cirrus Sac.

1. *The Testis* (Pl. XXVII. fig. 5; Pl. XXVIII. figs. 1–6, *t*) is situated on the dorsal surface of the intestine; it is an unpaired, long, very thin walled sac, extending from a point some 4–5 mm. behind the head, to within about 1 mm. of the posterior extremity, where it ends in a mass of small parenchymatous cells, which lie on the dorsal aspect of the intestine. Its greatest breadth (measured from side to side) is 0·7 mm., whilst its thickness (dorso-ventral) will be rather more than one-third of this.

The wall of this gland consists of a thin, and to all appearance, structureless membrane, which becomes very deeply stained by hæmatoxylin, and measures 0·004 mm. in thickness. It is attached to the dorsal wall of the body-cavity by a thin cellular mesentery (Pl. XXVIII. fig. 3, *m.e*) which is precisely similar in structure to those supporting the intestine, already described.

In the immature specimens under consideration, the gland contained only

* LIÉNARD, "Constitution de l'anneau œsophagien," *Archiv. d. Biol.*, t. i. p. 381, 1880.

a few masses of protoplasm of very variable size and shape, each usually possessing several nuclei, but not divided into distinct cells (fig. 2); they clearly represent the earlier stages in the development of the spermatozoa as figured by LEUCKART.* Anteriorly, as well as posteriorly, the testis becomes narrower though not to the same extent, and its inferior wall becomes thickened by a deposition of small cells on its outer surface. Farther forward two grooves appear in this mass of cells, which gradually become deeper until eventually they become roofed in, and thus converted into two tubes (figs. 4 and 5). The tissue in which these tubes lie is composed of small rounded cells, which vary from 0·004 mm. to 0·008 mm. in diameter, and are provided with small spheroidal nuclei. In the tubes they seem to form a single layer of columnar epithelium, but this was so badly preserved that I can give no further particulars concerning it.

The lumen of these tubes gradually becomes regularly oval and very much smaller, being in some sections barely perceptible, and in certain cases the cells seem to have a tendency to segregate into a separate covering for each tube, as indicated by a splitting in the cell mass; these fissures do not, however, extend far, and may be due only to the shrinking of the tissue in hardening (fig. 6).

On examination of Pl. XXVIII. figs. 4–6, it will be noticed that the cavity of the testis extends forwards some distance over this tube, but it becomes gradually smaller and eventually terminates blindly.

These two tubes continue separate although enclosed within a common investment for a distance of 0·2 mm., and then fuse into a thinner walled cavity, roughly oblong in section, and supported by a continuation of the same mesentery as the testis. At this point we may consider the second part of the genital tract to begin.

The two tubes are, of course, indications of the primitive symmetry of the sexual organs, and it may be worth while to mention that in *L. tænioides* the testis is double (though both glands eventually open into an unpaired tube), while in *P. oxycephalum* and *P. proboscideum* only a single gland is present.

2. *The Vesicula seminalis* (Pl. XXVIII. fig. 1, *v.s*), (Samenblase, Leuckart). I apply this name to the structures now to be described, because they seem to correspond to a tube, bifurcated at its extremity in *L. tænioides*, and near its commencement in *P. proboscideum*. In the present instance the lumina of the two tubes become united, and also first enlarged, for as may be seen by comparing figs. 6 and 7, the cavity of the single vessel is much greater than those of its two components. The wall is made up of cells of precisely the same character, but is only about 0·024 mm. in thickness on the average. The layer of columnar epithelium is distinct in its interior.

* *Loc. cit.*, Tab. ii. fig. 14.

After a course of about 0·01 mm. this vesicula seminalis becomes divided into two by a septum which rises from its ventral surface (fig. 7), and very shortly it divides into two quite distinct tubes (figs. 8 and 9). This junction between the two vesiculæ seminales is of considerable morphological interest, because it is the first trace of a condition which is carried further in *P. proboscideum*, and reaches its fullest expression in the large median sac found in *L. tænioides* (*cf.* LEUCKART, *loc. cit.*, Tab. ii. figs. 9 and 10).

At this point the dorsal mesentery splits, and a portion accompanies each tube.

The two branches of the vesicula seminalis now diverge from each other, and passing round the intestine, become united with the copulatory apparatus which lies upon its ventral surface; as they separate they first of all lose their mesenteric connection with the dorsal body-wall, although the rudiment of the mesentery is still to be seen after they have become detached from it. In their further course they approach the hook-glands, which they gradually traverse, passing through the middle of the gland and not between it and the intestine.

The rudimentary mesentery now demands a moment's notice; it passes forwards, becoming slightly wider, and just at the point where the vesicula seminalis emerges from the hook-gland, it becomes connected with this latter; so that now each hook-gland is supported by two mesenteries, one which it has had throughout the whole length of the body, and another which it has derived from the genital organs.

In this connection it may be well to say a word or two with respect to the size and structure of the vesicula seminalis. It is about 2 mm. long, and of a regular oval section, its greater and lesser diameters being 0·178 mm., and 0·1 mm. respectively, being slightly larger about the middle of its length. Its wall is made up of two layers of about equal thickness (0·02 mm.); the outer of which consists of a mass of cells very similar to those mentioned at its commencement, but rather more irregular in outline, and varying considerably in size, and provided with distinct ovoid nuclei. The inner coat consists of a single layer of elongated columnar epithelial cells, also nucleated and separated from each other by an undulating boundary line.

The vesicula seminalis now lies free in the body-cavity for a short distance, and then becomes attached to the vas deferens, which will be presently described.

At this point one of the most remarkable peculiarities in the organisation of the animal comes into notice. The lumen of the vesicula seminalis becomes excluded, and is not continuous with that of the vas deferens.

This last is a tube regularly elliptical in section, of sharply-defined even contour and compact walls; applied to the dorsal wall of this is a mass, oval in section, of much looser tissue, which is in fact the wall of the vesicula seminalis,

but there is no intimate union between the two, which are separated by a clear line of demarcation.

The truth of this observation, so exactly opposed to what might have been expected, has been confirmed by the preparation of a very careful series of transverse sections, which show the one tube lined with a perfectly smooth layer of epithelium, passing by the other, utterly ignoring, if the expression may be allowed, its proximity, while the vesicula seminalis fades away in a mass of rather loose cells without showing the least desire to unite with its companion.

Pl. XXVIII. fig. 15, shows the last section which contains a trace of the vesicula seminalis, in the one next behind the lumen, though small, was quite apparent, and in the next anterior there is no trace of it whatsoever.

Observations suggested by this arrangement will be deferred until the next portion of the generative system has been described.

3. *The Vas deferens* (Pl. XXVIII. figs. 1, 10, and 12, *v.d*) is a short tube which passes forwards from the termination of the vesicula seminalis and opens into the cirrus sac; this portion of it is about 1·5 to 2 mm. in length, but it is prolonged backwards into a cœcal process (blindschlauchartiger Anhang, Leuckart) whose length commonly exceeds that of the anterior portion by two to three times; it is variously curved, and in one case was observed to open again into itself, and thus to form a complete tubular ring.

The structure of this vessel is the same throughout, its average diameter is about 6·08 mm., that of its lumen 0·024 mm.; within it is lined by a thin layer of chitin derived from the external covering of the body, externally to which is seen a compact mass of nucleated cells radially disposed and to all appearance epithelial in nature. I was unable to discover with certainty the presence of muscular elements in this wall, although Leuckart observed them in *L. tænioides*, and based upon that fact the hypothesis that the cœcal prolongation is an organ for the propulsion of the semen.* For the greater part of its length it possesses a further adventitious covering of tissue similar to that in which the vesicula seminalis terminates.

The opening of this organ into the cirrus sac will be described under that heading (p. 185).

The want of continuity between the vesicula seminalis and the vas deferens becomes comprehensible when we consider what is known of the developmental history of this group of animals, for it would appear from the researches of Leuckart that one portion of the generative apparatus takes origin by the segregation of cells within the body, while another portion is formed by invagination of the external surface. When it is remembered that the vas deferens is connected with the external surface, and bears further marks of its origin in its chitinous lining, and that the vesicula seminalis presents a marked

* *Loc. cit.*, p. 75.

contrast in appearance, and has no such lining, it would seem justifiable to assume that the point where these two come into relation with each other is also the point where what may be termed the inward and outward growing portions of the generative apparatus meet. Furthermore, the immaturity of the specimens before us, indicated by their encysted condition, is in support of this, for it is quite conceivable that, as sexual maturity approaches, a connection might be formed between these two canals. It is to be noted, however, that in LEUCKART'S figures of the sexual organs of *L. tænioides*, the channel is shown as quite pervious from the exterior to the testis even in so early a stage as that known as *P. denticulatum*,* which measures only 4·5–5 mm. in length; but in describing the stage immediately preceding, which has a length of 3 mm., he mentions that the communication with the cirrus sac and the hinder portion was not clearly observed ("Eine Communication mit den dahinter gelegenenen Leitungsapparaten wurde mit Bestimmtheit nicht beobachtet").† If this explanation be the correct one, it is curious that the species before us should present such a striking embryonic feature when the remainder of its organisation has attained such a comparatively advanced stage of development.

4. *The Cirrus Sac* is shown in longitudinal section in Pl. XXVIII. fig. 10, and may be seen to be roughly divisible into two portions,—a solid part through which the vas deferens passes, situated on the dorso-lateral aspect, and a hollow part placed nearer to the ventral line. The latter portion is, speaking roughly, ovoid in form and slightly flattened in the radial direction of the animal's body, as seen in the section (fig. 11); anteriorly it gives off a tube from either side (fig. 10). One of these is the *ejaculatory duct*, the position of whose aperture near the middle line of the body has been already described; its lumen becomes gradually smaller until it reaches 0·005 mm.

The other tube-duct of what seems to be a gland, which, under the name of *accessory*, will be presently described.

The wall of this saccular portion is on the average about 0·036 mm. in thickness; its innermost layer is of chitin so thin that it appears only as a fine though very distinct line under a power of 400 diameters; next follows an epithelial layer, 0·008 mm. in thickness, of nucleated columnar cells; the remainder of the wall being composed of small cells among which run a number of muscular fibres, these last being confined to the anterior portion of it.

The solid portion of the cirrus sac is an ovoid mass somewhat smaller than the other part, the wall of which covers it to a certain extent, though eventually it fuses with it. Through the middle of this mass of cells passes the canal of the vas deferens, slightly widening as it approaches the sac until it ends in a short groove (Pl. XXVIII. fig. 10; also in section fig. 11, *v.d*).

A short distance posterior to this is another orifice leading into a cavity

* *Loc. cit.*, Tab. iv. fig. 11.

† *Loc. cit.*, p. 134.

which contains the "Chitinzapfen" of LEUCKART (fig. 10, *c.z*). This is a cylindrical body, pointed at its free extremity, and for the greater part of its length attached by one side to the interior of the cavity in which it lies (fig. 12, *c.z*); this cavity is only just large enough to contain the organ, whence in section its lumen appears as a slit almost annular in form. Between this part of the cell-mass and that which contains the vas deferens there is very often a fenestra, as in the case shown in the drawing.

With respect to the structure of this portion of the cirrus sac, it consists in the main of small (0·002–0·005 mm.) nucleated cells, closely packed. In the "Chitinzapfen" these show a tendency to a radial arrangement, and often leave in the centre an irregular gap, which does not seem, however, to be of any morphological signification.

The epithelial lining of the vas deferens here assumes a most distinctly radial arrangement (fig. 12, *v.d*), the cells being very long and slender, and with nuclei either at one extremity or the other, rarely in the middle; externally to this is a thinner layer of cells, which is an extension of the common wall of the cirrus-sac.

Of the cirrus itself I could find no trace whatsoever, and am consequently led to imagine that it has not yet made its appearance; if this be so, we have here another point in which this animal corresponds with a very early stage of *L. tænioides*. It is possible, however, that in this species no cirrus is ever formed, and that the "Chitinzapfen" does duty as a copulatory organ; in any case, I should be disposed to regard this as a kind of dilator for opening up the sexual canal, either for the immediate flow of the semen, or as a preparation for the passage of the slender cirrus, which by itself would hardly seem to be fitted for such a purpose. In this process a very important service would be rendered by the muscles which pass transversely across the sides of the cirrus sac, for they would approximate the "Chitinzapfen" to the sexual orifice.

The *Accessory Gland* (Pl. XXVIII. fig. 13), above alluded to, is a flattened mass of cells lying beside the intestine about the spot where the œsophagus enters it, and stretching in a dorsal direction as far as the hook-gland. The duct passes upwards and forwards through the middle of it, and is surrounded by a space, crossed by numerous fine threads which are probably minute ramifications of the duct, although it could not be made out with certainty that they were hollow. At the extremities of these are groups of cells (0·008–0·014 mm. in diameter), rendered polyhedral by mutual pressure, and provided with relatively large nuclei, in some of the larger cells 0·008 mm. in diameter.

As to the secretion of this gland and its function, I have been able to make no observations.

The Female Organs.

But little is to be said on this subject, because these organs were in a very unsatisfactory state of preservation. They consist of—

1. The Ovary.
2. The Oviducts.
3. The Receptacula Seminis.
4. The Vagina.

1. *The Ovary* (Pl. XXVIII. fig. 18) occupies a position exactly corresponding to that of the testis, but is very much smaller. It is in fact at this stage of the animal's growth merely a narrow tube, about 0·015 mm. in diameter, passing with a sinuous course down the median dorsal line. It is attached by a mesentery similar in structure to, but much thicker than, those which support the testis and intestine (Pl. XXVIII. figs. 3, 14, &c.).

It consists of a thin layer of small nucleated cells, and has a considerable lumen; but I was unable to make out anything regarding the development of the ova.

2. *The Oviducts* are two in number, and like the vasa deferentia, pass round the intestine, and eventually meet in the middle line below it (Pl. XXVIII. fig. 16, *o.d*), where they open into the vagina.

In structure they seem to resemble the ovary itself.

3. *The Receptacula Seminis* (Pl. XXVIII. fig. 16, *r.s*) are two flattened oval sacs, nearly 1 mm. in length, and situated one on either side of the middle line immediately posterior to the oviducts. Anteriorly, and towards the median line, the cavity of the sac enlarges, and into this dilated portion projects a papilla on which opens, by a stellate orifice, the tube by which the sac communicates with the vagina.

The cuticular lining of the vagina could be followed to this orifice, but I could find no trace of it on the interior of the sac; the wall of which consists of a very compact mass of minute nucleated cells; it is about 0·025 mm. thick on the average, and is lined with what appear to be the remains of an epithelial layer.

4. *The Vagina* (Pl. XXVIII. fig. 16, *v*) is simply a narrow tube, which passes directly backwards from the point of union of the oviducts to open in the ventral line within a millimetre of the anus. Typically it lies in the ventral median line, but in one specimen of which I made sections, it lay at one side, between the hook-gland and the muscles of the body-wall.

It has a lumen of about 0·008 mm., and is lined by a delicate layer of cuticle, immediately external to which is found as usual a layer of columnar epithelial cells. These again are surrounded by another layer, made up of

rounded nucleated cells about two deep, and having a diameter of some 0·007 mm.

Systematic Position.

The parasite which has just been described finds its nearest congener in *Pentastomum polyzonum*, Harley.* It is distinguished from it, however, by the number of segments, which in the females under consideration amounts to 18–22, whilst in the adult females of *P. polyzonum* hitherto described † it does not exceed 19, and it is very unlikely that an immature form should have more, though it would very probably have fewer segments than the adult. In this case the difference in size is of course valueless as a specific character.

I propose therefore to make the specimens above described the type of a new species, whose diagnosis would be provisionally as follows:—

Pentastomum protelis, n. sp.

Body cylindrical in the anterior half, slightly tapering posteriorly, terminal segment obtusely pointed. No clear distinction between cephalothorax and abdomen. Head hemispheroidal, equal in diameter to the body. Mouth furnished with a papilla, perhaps a protrusible proboscis. No accessory hooks. Stigmata arranged in numerous irregular rows on all the segments. Male, 13–17 *mm. in length, with* 16 *or* 17 *annuli. Female,* 20–25 *mm. in length, with* 18–22 *annuli. Habitat, the mesentery of* Proteles cristatus, *enclosed in a connective tissue cyst.*

It is, of course, possible that some future investigator will demonstrate the identity of this form with an early stage of *P. polyzonum*, and this possibility is increased by the fact that specimens of this species were found in an African serpent,‡ of which part of the globe *Proteles cristatus* is also an inhabitant.

If such should be the case, Leuckart's opinion that *P. Diesingii*, v. Ben., is the immature form of this would be untenable, for this form exhibits distinctions in its body form, oral papilla, and muscular system, sufficient to prove its specific distinctness from the subject of this paper.

I propose now to make a few concluding observations on the subdivision of the family Pentastomidæ.

In the brief systematic portion of Leuckart's § work, the species are grouped under two headings, which are regarded as being of sub-generic value—

* *Proc. Zool. Soc. Lond.*, part 25, p. 115, 1857.

† Bᵐᵉ L, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. vi p. 176, 1880.

‡ Beli. *loc. cit.* p. 173. § *Loc. cit.* p. 152.

Linguatula, "Corpus depressum." "Cavitas corporis in latera annulorum porrecta, pectinata."

Pentastomum, "Corpus teretiusculum. Cavitas corporis continua."

It appears to me, however, that we see now sufficient anatomical distinctions in the works of previous authors,* and in the research which has just been recorded, to justify the elevation of these two groups to the position of distinct genera.

In the first group, for example, the hook-gland is diffuse, the œsophagus opens into the anterior termination of the intestine, the testis is double, and the vesicula seminalis single, while in the second group the hook-gland is collected into two masses, one on either side of the intestine; the œsophagus opens on the inferior surface of the intestine, the testis is single, and in most cases the vesicula seminalis seems to be double (*P. oxycephalum* would appear to be an exception).

It would seem only reasonable to suppose that such an amount of difference in structure ought to be anatomically expressed by at least a generic difference; but further investigations into the anatomy of other members of the group are very desirable to show whether they agree in the possession of these characters.

With respect to the names which these divisions should have, I do not think it possible to improve upon those suggested by Leuckart. As van Beneden has pointed out,† *Linguatula* has a claim to recognition on the score of priority, having been applied by Fröhlich‡ in the case of *L. serrata*.

The two genera would then be diagnosed thus, the characters of the family remaining as given by Leuckart:—

Linguatula, Fröhlich.

(Type, *Pentastomum tænioides*, Rudolphi.)

Body flattened; body cavity sending out lateral processes into the annuli; hook-gland diffuse; opening of œsophagus into the extremity of the intestine; testis double; vesicula seminalis single.

Pentastomum, Rudolphi.

(Type, *P. proboscideum*, Rudolphi.)

Body cylindrical; body cavity even, without lateral prolongations; a hook-gland on either side of the intestine; testis unpaired; vesicula seminalis single (?).

* Van Beneden, *Ann. Sci. Nat.*, sér. 3 (Zool.) t. xi. p. 313, 1849; Diesing, *Ann. des Wien. Mus.*, Bd. i. p. 1, 1836.

† *Loc. cit.*, p. 314.

‡ Fröhlich, *Naturforscher*, Bd. xxiv. p. 148, 1789 (*fide* Diesing).

EXPLANATION OF THE PLATES.*

Explanation of Reference Letters the same in both Plates.

a.g, accessory gland; *a.g'*, duct of same.
a.n.c, anterior nervous commissure.
c.s, cirrus sac.
cu, cuticle.
c.z, "Chitinzapfen."
ep, epidermis.
g.o, genital openings.
h.g, hook-gland; *h.g'*, duct of same.
i, intestine.
me, mesentery.
m.l, longitudinal muscles.
m.o, oblique muscles.
m.t, transverse muscles.
n, nerves.
n.g, nerve ganglion.
nu, nucleus of sarcolemma.
œ, œsophagus.
o.d, oviduct.
o.p, oral papilla.
ov, ovary.
par, subepidermic cellular layer.
p.c, parietal cells.
r.s, receptaculum seminis.
s.c, stigmatic cells.
t, testis.
v, vagina.
v.d, vas deferens; *v.d'*, cœcal portion of same.
v.s, vesicula seminalis.
u.e, extensor unci muscle.
u.f, flexor unci muscle.
u.f.a, flexor accessorius unci muscle.
u.r, retractor unci muscle.
u.b.a, adductor basis unci muscle.
u.b.p, protractor basis unci muscle.

PLATE XXVII.

MUSCLES, DIGESTIVE AND SECRETORY ORGANS.

Fig. 1.—View of *Pentastomum protelis*, ventral surface (small male specimen).
Fig. 2.—Surface view of the cuticle.
Fig. 3.—Hooks: *l*, lateral; *m*, median.
Fig. 4.—Side view of oral papilla.
Fig. 5.—Transverse section of intestine and mesenteries, with posterior portion of testis.
Fig. 6.—Transverse sections of œsophagus.
Fig. 7.—Transverse section of rectum.
Fig. 8.—Median longitudinal section of head.
Fig. 9.—Transverse section of body-wall.
Fig. 10.—Transverse section of body, posterior to union of vas deferens and vesicula seminalis.
Fig. 11.—Stigmatic cells.
Fig. 12.—Muscles of hook.
Fig. 13.—Transverse section near the posterior extremity.
Fig. 14.—View of transverse muscles.
Fig. 15.—Large glandular cells from the body-wall.
Fig. 16.—Terminations of muscular fibres in the cuticle.
Fig. 17.—Arrangement of muscles are seen from within the body-cavity.

* The drawings were for the most part made by the aid of the camera with Zeiss' microscope. The magnifying power employed is marked on the plate beside every drawing.

Plate XXVIII.

Generative Organs.

Fig. 1.—General view of male organs.
Fig. 2.—Portion of contents of testicle.
Figs. 3–7.—Transverse sections of testis at different points as far as the commencement of the vesicula seminalis.
Fig. 8.—Section of vesiculæ seminales prior to the separation of the two tubes.
Fig. 9.—Section of vesiculæ seminales after the separation.
Fig. 10.—Longitudinal section of cirrus sac.
Fig. 11.—Transverse section of cirrus sac along the line *x x*.
Fig. 12.—Transverse section of cirrus sac along the line *y y*.
Fig. 13.—Transverse section of accessory gland and duct.
Fig. 14.—Transverse section of vesicula seminalis, hook-gland, &c.
Fig. 15.—Transverse section of vas deferens at the point of termination of the vesicula seminalis.
Fig. 16.—General view of part of the female organs and nervous system.
Fig. 17.—Longitudinal section of the receptaculum seminis.
Fig. 18.—Transverse section of ovary and its mesentery.

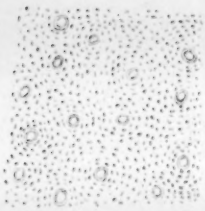


Fig 2. 4f



Fig 1. 4



Fig 3. 4f



Fig 4. 4

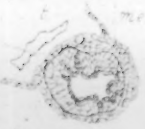


Fig 5. 4



Fig 6. 4f Fig 7. 4



Fig 8. 4f

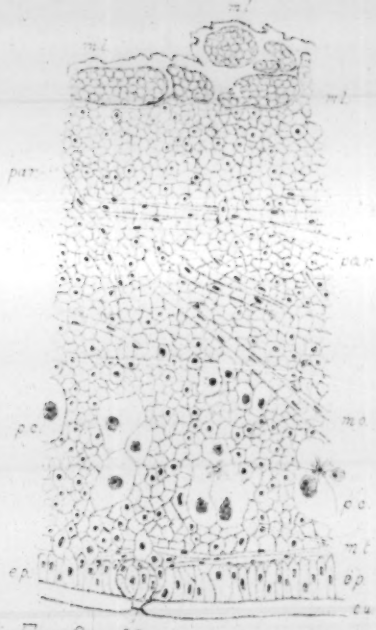


Fig 9. s.c. 250



Fig 10. 4f

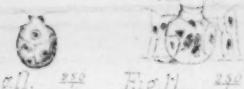


Fig 11. 250 Fig 12. 250

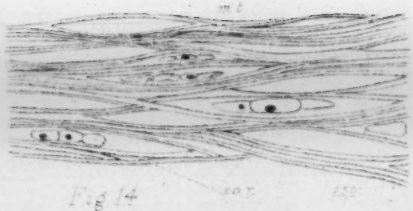


Fig 14. 250

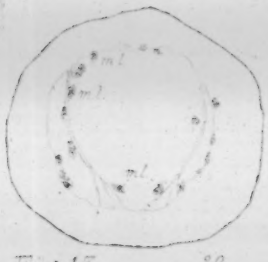


Fig 13. 20

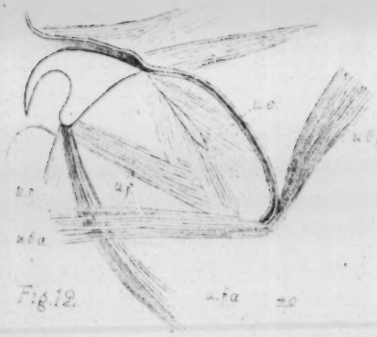


Fig 12. 20

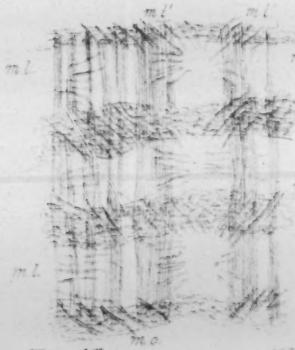


Fig 17. 100



Fig 15. 250



Fig 16. 250

ANATOMY OF PENTASTOMUM PROTELIS.

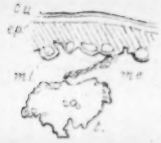


Fig 3.



Fig 2.



Fig 1.



Fig 6.



Fig 7.



Fig 4.



Fig 8.



Fig 5.



Fig 11.

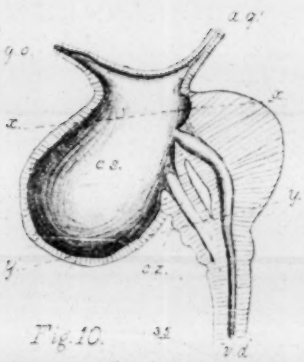


Fig 10.



Fig 9.



Fig 12.



Fig 13.



Fig 14.



Fig 15.

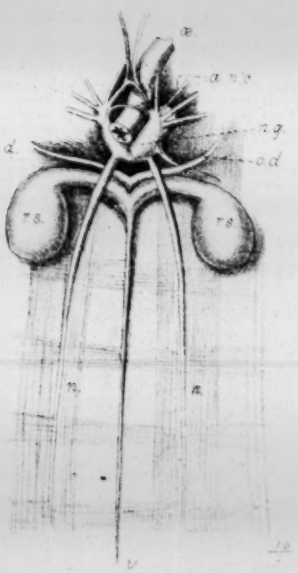


Fig 16.



Fig 17.



Fig 18.

ANATOMY OF PENTASTOMUM PROTELIS

XI.—*On Superposed Magnetisms in Iron and Nickel.* By Professor C. G. Knott, D.Sc. (Plate XXIX.)

(Read 2nd July 1883.)

The experiments which form the subject of this paper are designed, in the first place, to test the relation pointed out by Maxwell* between Joule's discovery of the lengthening of iron in the direction of magnetisation,† and Wiedemann's later researches into the twisting of iron under the influence of longitudinal and circular magnetisations,‡ and, in the second place, to investigate the corresponding properties of nickel.

According to Joule's discovery, an iron bar or wire lengthens in the direction of magnetisation, and contracts in directions at right angles thereto. The extension is greater for a stronger magnetising force, and, if the metal is subjected to traction in the direction of lengthening, is smaller for a greater traction. In the experiments to be described a wire was fixed at its upper end, and stretched vertically by means of an appended mass. It passed centrally through a glass tube of nearly the same length, round which a helix of wire was wound. The length of the helix was 34·3 centimetres, and the total number of coils 196. A current passed through the helix magnetised the wire longitudinally. At the lower end of the wire was fixed a short copper wire, which dipped into a pool of mercury. By this means a current could be passed along the wire so as to magnetise it circularly. The twist produced under the joint influence of the longitudinal and circular magnetisations was measured by the deflection of a spot of light focussed upon a millimetre scale after reflection from a mirror attached to the lower end of the wire. Both the magnetising currents were measured on a Helmholtz tangent galvanometer.

The method of experimenting was as follows:—One of the currents was kept steady, while the other was varied through a considerable range. When both currents were flowing the free end of the wire came to rest in a definite position, which was registered by the reading on the scale. One of the currents was then reversed, and a second reading obtained. The difference between these readings was approximately four times the angle of twist. By successive

* See Maxwell's *Electricity and Magnetism* (2nd edition, vol. ii. § 448). The first edition comes to a wrong conclusion, in consequence of a misprint in Wiedemann's *Galvanismus* (1st edition, Bd. ii. § 491). See also Chrystal's article on "Magnetism" in the *Encyclopædia Britannica* (vol. xv. pp. 269, 271).

† Sturgeon's *Annals of Electricity*, vol. viii. p. 219; and *Phil. Mag.*, 1847.

‡ Wiedemann's *Galvanismus*, 1st edition, Bd. ii. § 491.

reversings and re-reversings of the current, a series of readings was obtained whose differences gave a good mean. From the numbers so deduced the true twist expressed in radians was easily calculated.

The first experiments were made with an iron wire, ·00435 square centimetres in cross section. The most important are those in which the current along the wire (the linear current) was kept constant, while the helical current was made to vary from under half an ampère to nearly six ampères. Five different series were taken with different values of the steady current. In the following tables the upper row gives the successive values of the helical currents in ampères, and the lower the corresponding twists in radians $\times 10^5$.

GROUP A.

Experiment I. Linear Current = ·575 Amp.

Helical Current,	0·377	0·741	1·289	2·045	2·573	5·019
Twist, . .	234	489	629	672	663	625

Experiment II. Linear Current = ·723.

Helical Current,	0·368	0·758	1·289	1·676	2·025	2·436	2·902	3·375	5·019
Twist, . .	307	597	816	877	907	900	881	832	703

Experiment III. Linear Current = 1·891.

Helical Current,	0·393	0·741	1·254	1·566	1·987	2·488	2·925	3·527	4·068	5·781
Twist, . .	372	762	1179	1335	1389	1389	1387	1345	1279	1077

Experiment IV. Linear Current = 3·157.

Helical Current,	0·460	0·700	1·254	1·991	2·488	3·157	4·592
Twist, . .	342	775	1251	1567	1680	1710	1652

Experiment V. Linear Current = 4·068.

Helical Current,	0·410	0·700	1·254	1·891	2·385	3·039	4·214
Twist, . .	390	810	1303	1678	1802	1886	1884

Three series were taken with steady helical current and varying linear current. They are as follows :—

GROUP B.

Experiment I. Helical Current = ·611 Amp.

Linear Current,	0·410	0·716	1·272	1·943	2·395	3·051	3·899
Twist, . .	126	357	742	1030	1125	1197	1225

Experiment II. Helical Current = 1·987 Amp.

Linear Current,	0·418	0·750	1·276	1·948	2·364	2·970	3·803
Twist, . .	127	312	767	1190	1358	1576	1754

Experiment III. Helical Current = 3·229.

Linear Current,	0·505	0·893	1·320	1·703	2·724
Twist, . .	152	387	718	877	1367

In both these series the wire was under a tension of 1950 grammes' weight. The representative curves are shown on Plate XXIX., iron groups A. and B. The current strengths of the varied current are laid down horizontally, and the corresponding twists vertically. The two series differ markedly, the A group showing a maximum twist for an intermediate current strength, the B group giving no such indication. That such a difference between the two cases should exist is not to be wondered at, since the magnetisation due to a

linear current follows a different law from that due to a helical current. Indeed, it is impossible to magnetically saturate an iron wire by means of a linear current. Further than this, experiments of the B type need no discussion.

The maximum point in the curves of group A is a constant characteristic of all similar cases, as will be seen by reference to the curves of groups C and D. These represent further experiments with iron wires, in which is studied more particularly the effect of tension upon the amount of twist. In the following tables there are three distinct series under each experiment corresponding to three different tensions. The last column contains the tensions expressed in grammes' weight.

GROUP C.—Cross Section of Iron Wire = ·00276 sq. cc.

Experiment I. Linear Current = ·533 Amp.

Helical Current,	0·952	1·657	2·489	3·039	3·723	5·198	Tension.
Twist,	561	632	632	607	523	413	1360
	1013	1148	1161	1097	1013	875	712
	1123	1284	1258	1265	1097	923	388

Experiment II. Linear Current = 1·476 Amp.

Helical Current,	0·533	0·952	1·657	2 489	3·039	3·723	5·198	Tension.
Twist,	484	1213	1471	1484	1406	1299	1097	1360
	458	1077	1452	1594	1529	1426	1187	712
	439	1045	1503	1658	1684	1561	1323	388

Experiment III. Linear Current = 2·412 Amp.

Helical Current,	0·533	0·952	1·657	2·489	3·039	3·723	5·198	Tension.
Twist,	0484	0877	1332	1445	1510	1555	1394	1360
	0490	1187	1742	1974	1974	2019	1800	712
	0394	0923	1394	1723	1820	1800	1645	388

GROUP D.—Cross Section of Iron Wire = ·000714 sq. cc.

Experiment I. Linear Current = 0·65 Amp.

Helical Current,	0·508	0·995	1·593	2·262	2·615	3·157	4·068	Tension.
Twist,	103	290	368	348	336	329	265	388
	142	400	613	619	613	574	484	258
	129	484	697	761	787	761	723	129

Experiment II. Linear Current = 0·973 Amp.

Helical Current,	0·508	0·995	1·593	2·262	2·615	3·157	4·068	Tension.
Twist,	...	...	794	839	865	807	774	388
	...	...	923	1090	1077	1013	884	258
	252	613	916	1045	1123	1084	1045	129

The direction of twist was as found by WIEDEMANN. If the current is passed down the wire from the fixed to the free end, and the wire is magnetised with north pole downwards, the free end, as looked at from above, twists in the direction of the hands of a watch. As pointed out by MAXWELL and CHRYSTAL, this agrees with JOULE'S discovery mentioned above. For the circular magnetisation due to the down current is right handed with reference to the current. Hence the resultant magnetisation lies in a direction intermediate to the circular and longitudinal magnetisations at any point; and as the iron extends in the direction of magnetisation, and contracts at right angles thereto, there will be a lengthening of the wire in a direction oblique to the axis, such as to cause a twist in the direction specified. The amount of twist depends not only on the magnetising force in this oblique direction, but also upon the obliquity, so that a maximum twist for an intermediate value of the helical current is quite in accordance with JOULE'S result that the extension increases with the magnetisation. Suppose, for example, that the circular and longitudinal magnetisations at a point on the wire are α and β, and that these give a resultant magnetisation $\sqrt{\alpha^2+\beta^2}$ in a direction making an angle, whose tangent is α/β, with the vertical line through the point. Let the extension along this direction be represented by $\mu\ (\alpha^2+\beta^2)$, an assumption approximately

true according to JOULE's researches. Then the amount of twist per unit length of the wire will be

$$\tau = \mu(\alpha^2 + \beta^2)\alpha/\beta = \mu(\alpha^3/\beta + \alpha\beta).$$

If α is constant, τ has a maximum value when

$$\beta = \alpha.$$

If β is constant, there is no such maximum value of τ. A comparison of curves A and B (Plate XXIX.) bear this out fully.

Hence, in the case of constant circular magnetisation and varying longitudinal magnetisation, the twist will first increase and then diminish as the latter is increased to its saturation point. For a stronger circular magnetisation the maximum point is pushed further on, until, when the circular magnetisation has reached the saturation point, there will be no subsequent fall off in the twist, *i.e.*, no true maximum point. These remarks apply strictly to a thin iron cylinder. In the case of a wire the effects are complicated. Still the curves on Plate I. bear out in a remarkable way these conclusions. Thus in fig. A the maximum point obviously occurs further to the right in the higher curve. In the following table a direct comparison between the linear current strength and the helical current strength, which corresponds to the maximum twist, is established :—

Linear Current, ...	0·575	0·723	1·891	3·157	4·068
Helical Current for Maximum Twist, .	2	2·2	2·4	3·1	3·5+

The highest curve has no distinctly marked maximum, a result in close agreement with the foregoing deductions. The other series of curves bear out the same conclusion.

JOULE also found that the extension for a given magnetisation was smaller when the wire was subjected to a greater tension. Hence, in general, we should expect the twist in a wire due to superposed circular and longitudinal magnetisations to be less for the greater tension, since the longitudinal extension will be diminished. This conclusion is quite borne out by curves C and D. With only one exception (namely, C III.) an increase in tension is accompanied by a decrease in twist. This result is not in accordance with WIEDEMANN'S, who found the twist to be nearly independent of the tension. Possibly, however, he worked with a thickness of wire which for the special combination of current strengths and tensions was not sufficiently sensitive to the change of tension. A glance at the curves C and D shows how much greater is the sensitiveness to tension change for certain combinations than for others.

JOULE further discovered that when the tension exceeded a certain value, there was contraction instead of extension in the direction of magnetisation. This ought to give in these experiments a reversed twist under tensions higher than this critical value. Of this, however, there was no indication, although the thicker iron wire broke under a tension of 2600 grammes' weight, and was, therefore, subjected in experiments A to a comparatively high tension.

It remains now to consider nickel. The experiments were conducted in precisely the same manner as in the case of iron. The following are the tabulated results for a nickel wire of cross section, ·0056 sq. cc., length 36 cc., and tension 1950 grammes' weight; first, for a steady linear current and varied helical current, and second, for a steady helical current and varied linear current. As before, the currents are in ampères, and the twists in radians $\times 10^5$.

GROUP A. (Linear Current Steady.)

Experiment I. Linear Current = 0·674 Amp.

Helical Current,	0·368	0·700	1·210	1·891	2·303	2·616	3·016	3·997
Twist, . .	109	200	429	765	952	1077	1206	1458

Experiment II. Linear Current = 0·995 Amp.

Helical Current,	0·307	0·410	0·741	1·276	1·680	2·084	2·594	5·384
Twist, . .	55	103	281	570	871	1052	1303	1897

Experiment III. Linear Current = 2·510 Amp.

Helical Current,	0·368	0·700	1·210	1·891	2·303	2·616	3·016	3·997
Twist, . .	152	263	596	1119	1415	1923	2145	2552

Experiment IV. Linear Current = 3·039 Amp.

Helical Current,	0·205	0·393	0·741	1·313	1·726	2·084	2·594	3·591	5·384
Twist, . .	90	74	436	948	1310	1553	1894	2345	2819

Experiment V. Linear Current = 4·441 Amp.

Helical Current,	0·205	0·451	0·783	1·298	1·750	2·084	2·594	3·565	5·479
Twist, . .	123	219	584	1145	1535	1797	2126	2626	3152

Experiment VI. Linear Current = 5·578 Amp.

Helical Current,	0·368	0·576	0·952	1·521	1·938	2·784	4·519
Twist, . .	171	345	855	1442	1736	2268	2987

Group B. (Helical Current Steady.)

Experiment I. Helical Current = 0·658 Amp.

Linear Current,	0·368	0·578	1·097	1·815	2·368	2·724	3·277	3·815	4·796
Twist, . .	39	74	132	234	383	505	702	897	1019

Experiment II. Helical Current = 1·891 Amp.

Linear Current,	0·327	0·582	1·141	1·891	2·891	3·463	3·927	5·019
Twist, . .	57	89	180	420	954	1371	1700	1991

Experiment III. Helical Current = 2·702 Amp.

Linear Current,	0·327	0·582	1·141	1·891	2·891	3·463	3·927	5·019
Twist, . .	29	89	216	457	1126	1545	1948	2322

Experiment IV. Helical Current = 2·405 Amp.

Linear Current,	0·893	1·520	2·323	2·812	4·334	4·680
Twist, . .	368	819	1355	1561	1865	1890

Experiment V. Helical Current = 3·338 Amp.

Linear Current,	0·867	1·494	1·797	2·298	2·702	3·277	4·519
Twist, . .	439	929	1226	1639	1909	2168	2374

The representative curves are shown on Plate XXIX., nickel groups A and B. The chief points of difference between the behaviour of iron and nickel are these: first, the direction of twist in the nickel is the reverse of that in the iron; and second, there is no maximum in the nickel A group of curves. The free end of the nickel wire twists in the direction opposite to the hands of a watch, as looked at from above, when the wire is traversed by a down current, and is magnetised with north pole downwards. This agrees with BARRETT's discovery,* that nickel contracts when magnetised. The possibility of a maximum, again, depends upon how the amount of contraction varies with the magnetisation, and also, since the abscissæ represent currents and not magnetisations, upon the relation which holds between these last.

The B curves are very similar in form to the B curves of the iron. It will be noticed that curve IV. of this series lies for the most part higher than curve III., although the steady helical current is smaller in the former; also that I., II., and III. seem to fall together, as belonging to the same set, while IV. and V. form a system by themselves. The reason of this would seem to be that between the dates, June 2nd and 4th, namely, on which these sets were taken, the nickel wire underwent some physical change. Probably this was of the nature of a change in temper, since on the latter date the nickel wire was for an instant traversed by a current of sufficient strength to make it glow red hot. Taking this consideration into account, and neglecting curve A, III., which is obviously a bad experiment, we conclude that the twist due to the superposition of circular and longitudinal magnetisations in nickel wire increases with

* See *Nature*, vol. xxvi. 1882.

either magnetisation, so that the amount of contraction of nickel when magnetised increases with the magnetising force.

The effect of varying tension was tried with two sizes of nickel wire—an intermediate size of ·002 sq. cc. cross section, and a thin wire of ·0002 sq. cc. cross section. The following are the tabulated results, the tensions being expressed in grammes' weight.

GROUP C.—Intermediate Wire.

Experiment I. Linear Current = ·533 Amp.

Helical Current,	0·517	0·995	1·703	2·594	3·216	4·140	5·779	Tension.
Twist,	...	131	265	374	432	465	639	712
	...	161	303	152	490	574	619	388
	39	168	219	555	626	826	871	258
	39	200	465	729	839	923	1000	64

Experiment II. Linear Current = 1·612 Amp.

Helical Current,	0·517	0·995	1·703	2·594	3·216	4·140	5·779	Tension.
Twist,	245	432	903	1400	1594	1852	2174	1360
	168	538	955	1439	1529	1768	2032	712
	136	555	1097	1490	1761	2052	2284	388
	142	384	1116	1652	1813	2149	2374	258
	71	465	1148	1768	2084	2297	2561	64

Experiment III. Linear Current = 2·489 Amp.

Helical Current,	0·517	0·995	1·703	2·594	3·216	4·140	5·779	Tension.
Twist,	181	394	871	1645	1725	2064	2568	2656
	155	697	1233	1832	2071	2348	2813	1360
	265	839	1561	1981	2207	2594	2942	712
	265	852	1619	1603	2110	2639	3084	388
	265	845	1697	2258	2490	2774	3103	258
	232	936	1897	2568	2877	3148	3407	64

GROUP D.—Thin Wire.

Experiment I. Linear Current = ·442 Amp.

Helical Current,	0·575	1·003	1·703	2·615	3·216	4·067	5·577	Tension.
Twist, . .	96	147	258	439	490	684	813	258
	200	394	813	1400	1774	2181	2961	194
	361	707	1510	2278	2755	3529	4497	129
	226	432	1000	1594	1903	1968	2170	97
	142	245	561	1045	1322	1613	1819	64

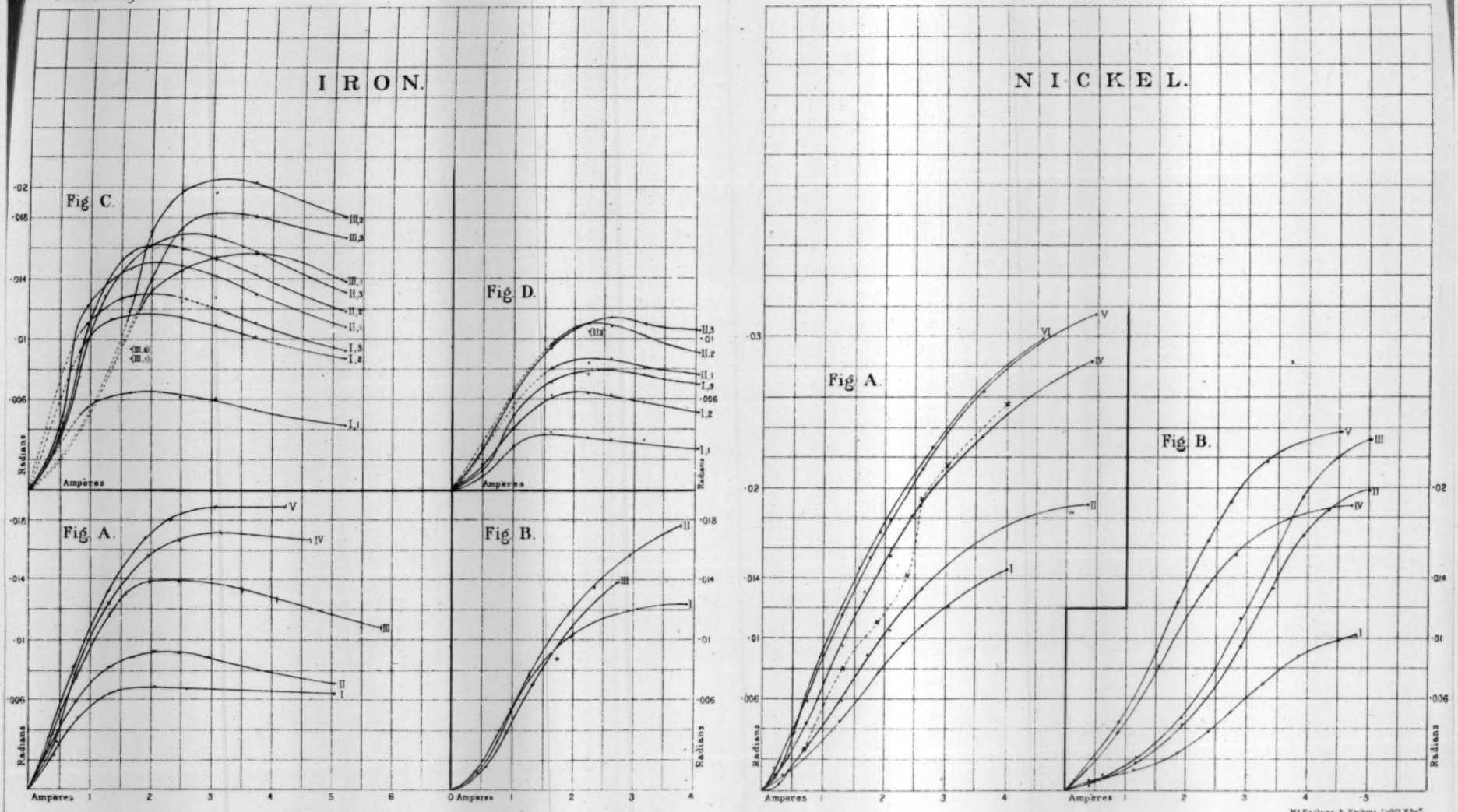
Experiment II. Linear Current = ·825 Amp.

Helical Current,	0·558	1·003	1·703	2·594	3·240	3·927	5·290	Tension.
Twist, . .	...	290	465	794	971	1335	1542	258
	187	368	464	1065	1258	1652	2103	194
	226	452	826	1161	1400	1897	2155	129
	452	987	1742	2619	3013	3471	3968	97
	458	1006	2052	2981	3155	3600	4090	64

Here also, as a glance at these numbers will show, increased tension is in general accompanied by diminished twist. Experiment D, I. is, however, quite exceptional, as the twist reaches a very pronounced maximum for an intermediate tension. With the same wire, and with the linear current nearly doubled in strength, this peculiarity quite disappears. It is impossible at present even to suggest an explanation.

The experiments described above were all made in the Physical Laboratory of Edinburgh University during the months of March, May, and June of this year. The object primarily aimed at was to establish the explanation given by MAXWELL and CHRYSTAL of WIEDEMANN'S torsion effect in iron under the influence of superposed magnetisms, and then to extend the same to the case of nickel. This, I think, has been effected. At the same time other facts have been brought to light, especially as to effect of tension, which will probably repay more careful study.

My thanks are due to Professor TAIT for providing me with the specimens of pure nickel wire, and to Professor CHRYSTAL for his ever ready and valuable advice.



SUPERPOSED MAGNETISMS IN IRON & NICKEL.

XII.—*On the Relative Electro-Chemical Positions of Wrought Iron, Steels, Cast Metal, &c., in Sea-Water and other Solutions.* By Thomas Andrews, Assoc. M. Inst. C.E., F.C.S. (Plates XXX. to XXXIV.)

(Read 15th January 1883.)

The experiments contained in this memoir were made by the author with the galvanometer on wrought iron, steel, cast metal, &c., bars and plates, arranged in galvanic circuit in sea-water and various other waters and solutions, to determine the relative electro-chemical position of these metals under such circumstances.

These varieties of the same metal iron are of such vast and universal utility that accurate information respecting any of the properties possessed by them cannot fail to be of interest.

A knowledge of the relative electro-chemical positions assumed by wrought iron, steels, and cast metal when in galvanic connection in sea-water is of importance as determining their respective liability to electrolytic disintegration when combined in marine works and structures, and a research of this kind presents features of interest capable of practical application in many ways.

When plates or bars of wrought iron, steel, &c., are connected in circuit and immersed in sea-water or other solution, and attached to a delicate galvanometer, an electric current is set up of varying power according to the difference of chemical composition or mechanical or physical properties, &c., of the wrought iron and steels employed.

The following experiments were undertaken by the author to measure, if practicable, the extent of this action, and to endeavour to determine the relative electro position of the various steels, wrought iron, and cast metal, with some degree of exactness.

Table A.

Analyses of Steel, Wrought and Cast-Iron Bars. Percentage Composition.

Description.	Graphitic Carbon.	Combined Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Tungsten.	Iron (by difference).
Soft Siemens-Martin steel,	...	...	...	...	...	...	...	...
Wrought iron, . .	...	Trace	·224	None	·239	·071	...	99·466
Soft steel (Firth's), . .	...	·570	·032	Trace	·066	·147	...	99·185
Bessemer steel, . .	...	·550	None	·032	·175	·216	...	99·027
Puddled steel, . .	...	·440	·144	·048	·149	Trace	...	99·219
Puddled steel (chilled), .	...	·490	·140	·004	·073	·215	...	99·078
Hard steel (Firth's), .	...	1·600*	·145	·002	·025	·183	...	98·045
Cast metal, . . .	2·400	1·000*	·570	·140	·580	·860	...	94·450
Tungsten steel, . .	...	1·750*	·135	·069	·139	·720	9·270	87·917

* By combustion.

One interesting fact observed in the course of these experiments is that wrought iron and steels, &c., are not static in their relative electro-chemical positions, and when immersed in sea-water, or other solutions in connection with each other, cannot exactly be regarded as constant elements. The relative electro-chemical position is also varied, according to the nature of the solutions employed.

The chemical composition of the iron and steel bars and plates employed in the following experiments is shown by the accompanying analyses.

TABLE B.

Analyses of Steel, Wrought and Cast-Iron Plates. Percentage Composition.

Description.	Graphitic Carbon.	Combined Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Iron (by difference).
Soft Siemens-Martin steel, .	...	·170	·071	·117	·077	·627	98·938
Soft steel (Firth's), . . .	...	·460	·074	·025	·210	·184	99·047
Wrought iron, . . .	...	Trace	·206	·024	·454	·396	98·920
Soft Bessemer, . . .	...	·150	·015	·111	·064	·540	99·120
Hard Bessemer, . . .	...	·510	·068	·113	·087	1·153	98·069
Hard Siemens-Martin steel, .	...	·720	·080	·102	·143	1·239	97·716
Hard steel (Firth's), . .	...	1·407*	·121	·056	·080	·360	97·976
Cast metal, ...	1·500	2·010*	·410	·250	·450	·650	94·730

* By combustion.

Some of the physical properties of the bars employed are indicated by the following tests to which they were submitted :—

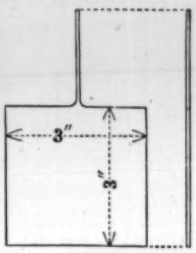
TABLE C.

Description	Original.		Ultimate Stress.		Fractured.				Stress per Square Inch of Fractured Area.	Extension in 10 Inches.		Appearance of Fracture.
	Size.	Area.	Total.	Per Square Inch of Original Area.	Size.	Area.	Difference. Area	Difference. Per Cent.		Inch.	Per Cent.	
	Inch.	Sq. in.	lbs.	Lbs. Tons.	Inch.	Sq. in.			lbs.			
Tungsten steel,	·30	·070	12,561	179,443 = 80·1	·27	·057	·013	18·6	220,368	0·73	7·3	10 % silky, 90 % granular
Hard steel, .	·298	·0697	10,967	157,346 = 70·2	·289	·0656	·0041	5·8	167,179	·12	1·2	100 % granular
Bessemer steel,	·297	·0693	9,851	142,150 = 63·4	·275	·0594	·0099	14·2	165,841	·16	1·6	100 % granular
Puddled steel,	·296	·0688	7,180	104,361 = 46·6	·257	·0518	·0170	24·7	138,610	·27	2·7	100 % silky
Puddled steel (chilled),	·298	·0697	6,322	90,703 = 40·5	·295	·0683	·0014	2·0	92,562	·07	0·7	35 % silky, 65 % granular
Wrought iron,	·296	·0688	6,028	87,618 = 39·1	·284	·0633	·0055	7·9	95,229	·11	1·1	100 % fibrous
Soft Siemens-Martin steel,	·38	·113	8,328	73,699 = 32·9	·25	·049	·064	56·6	169,959	1·97	19·7	100 % silky
Cast metal, .	·293	·0674	1,436	21,305 = 9·6	·293	·0674	·0000	0·0	21,305	·00	0·0	100 % granular (mottled)

Galvanometer Experiments.

The bars of wrought iron and steels, &c., used in the experiments were exactly $\frac{297}{1000}$ths of an inch (7·5 millimetres) in diameter, and were cut as test pieces from near the centre of bars of wrought iron and steel, manipulated as near alike as possible for purposes of comparison.

All the wrought iron and steel, &c., plates employed in the following experiments, except where otherwise described, were exactly three inches square (representing a total surface area of exposure of eighteen square inches for each plate, exclusive of the edges which were alike in each case), and were of uniform thickness, and in shape as shown in fig. No. 1.



Fig, 1.

The bars and plates were of the chemical composition and possessed of the general physical properties, as shown in the preceding tables, and with the exception of those covered with scale (magnetic oxide), were all smoothly polished bright.

The experiments on the various samples were conducted in each case in precisely the same manner for purposes of exact comparison, and very many times repeated, but in the same manner for corroboration, the results being derived from exactly corresponding experiments in each case, the bars and plates in the solutions being kept exactly the same distance apart, &c., in fact, every precaution was adopted to insure accuracy.

The records in the following tables of galvanometer experiments are the result of some 3000 carefully made observations by the author, some of which were thirty or forty times repeated to insure accuracy.

It should be understood that the following experiments do not represent fixed or permanent deflections; but they are the results of a number of observations made in precisely the same manner in each case for purposes of exact comparison between the various steels employed.

In cases where necessary the author has recorded the highest and lowest deflection noticed, in addition to the averages to illustrate the variations better. In the galvanometer experiments the bars and plates were all immersed, one pair at a time, in an equal measured quantity of sea-water, or other solutions, and placed in galvanic connection at equal distances apart. The wrought iron, &c., bar or plate, was connected with one terminal of a delicate galvanometer, to the other terminal of which was attached the bar or plate of steel, &c. The connections were made with insulated copper wires properly secured to the ends of the bars or plates with screw clips.

The measurement of the galvanic action is recorded in the tables.

[*Inserted April* 5, 1883.—The galvanometer selected for these experiments

was a low resistance galvanometer, with jewelled centre, accurately graduated throughout the circle.

To observe the fractional parts of degrees with accuracy, the author took the observations through a powerful lens fixed above the galvanometer, by means of which arrangement and from the author's experience in using it in this manner, and from repeated check experiments, it was found that variations of the needle could be taken to about the $\frac{1}{10}$th of a degree of deflection.

The galvanometer was examined by the Wheatstone Bridge arrangement with standard resistance coils, and the resistance was found to be 220 ohms.

A Daniells cell through a resistance of 9180 ohms (including the resistance of the galvanometer) gave a deflection of one degree, or $\frac{1}{9180}$th of an ampère produces a deflection of one degree (taking the electromotive force of the Daniells cell as unity).

From these observations, therefore, the strength of the electric current represented by the deflections recorded in this paper may be calculated; and as the resistance in the cells containing the sea-water would not exceed 3 ohms, an indication of the E.M.F. can be obtained.

In taking all readings the galvanometer was very carefully adjusted before each observation, and all deviations from vibration, tremor, or other causes, carefully guarded against; the greatest care was exercised in the experiments, the point of the needle being under constant observation, and the slightest variations were carefully watched as the differences to be dealt with in course of these experiments were sometimes small.

The author is satisfied that the observations recorded represent accurately differences arising from the nature of the metals and solutions employed.]

The experiments on bars, recorded in tables D, E, F, represent the average of the deflections observed on first immersion of the steel and iron bars in the sea-water, the bars on each repetition of the experiment being carefully washed and wiped dry before re-immersion.

A very marked feature in the other galvanometer experiments, recorded in table and diagram G, I, Plate XXXII. (these observations extending over longer periods of time), is the steadily changing deflections noticed from the commencement; this appears to indicate a tendency in the various steels and irons to polarise each other's electric action, so that in course of time, as submerged iron and steel becomes coated with oxides, galvanic activity is considerably reduced from its first force; but it does not wholly subside. When plates of iron and steel, &c., in galvanic connection were taken out of the sea-water (the oxides being washed off) and were re-immersed, the deflections of the galvanometer arose for a time, afterwards reducing again.

The experiments in this memoir indicate that the galvanic relationships of the various steels and wrought iron do not remain the same, in sea-water or other solutions, but they appear capable of an interchange of electro-chemical

position; for instance, in the experiment with the plates, some of the steel plates took a negative position compared with the wrought iron; but afterwards the position was reversed.

This change of electro-chemical position is a fact of considerable interest, and the author has therefore given as typical some of the full records of the deflections observed in some of the experiments between steels, wrought iron, cast metal, &c.

These diagrams, &c., illustrate this tendency in detail. A reference to some of the tables will also show that in many instances the interchange is greatly varied and influenced by the nature of the solutions in which the steels, &c., were immersed. When the steels, &c., were immersed in an acid solution instead of one containing neutral salts, such as sea-water, a noticeable result was, in some instances, an almost complete reversal of electro-chemical position. (See table and diagram G, I, Plate XXXII.)

Although the soft steel and Bessemer steel bars in table D are recorded thereon as in the negative position compared with wrought iron, this is not contradictory to the results of similar soft steels in table G, because the results in table D are the first deflections, whereas those in table G indicate the same negative position at the commencement of the experiment; but the electro-chemical position afterwards changes by prolonged exposure.

An explanation of this change in the electro-chemical position of the soft steels may be that, as the solution gradually penetrates and acts on the metal, it meets with crystalline networks of higher carbides, &c., and other constituents of varying composition, which would probably offer varying resistance to the action of the solution.

This view of the case would appear to derive support from the observations made "On the Microscopical Structure of Iron and Steel," by Henry Clifton Sorby, Esq., LL.D., F.R.S., from which it would appear that iron or steel of the finest manufacture cannot be regarded as of purely homogeneous composition.

The experiments recorded in the following tables were made not only with the object of endeavouring to ascertain the relative electro-chemical position of wrought iron, steels, and cast metal, but also to throw light, if possible, on the amount of galvanic action which takes place practically where these metals are combined in marine or other structures. It will be seen, therefore, that the observations are roughly arranged with this object.

Amongst other experiments, measurements were not only taken using zinc, copper, and wrought iron as standards in combination with iron and steel and cast metal, &c., but it will be also observed that bars and plates covered with magnetic oxide were employed, as practically the action of this oxide upon wrought iron, steels, and cast metal in sea-water, &c., is frequently a source of electrolytic disintegration, to ascertain the extent of which forms one object of the following experiments:—

TABLE D.

Galvanometer Experiments with Bright Steel, Wrought Iron, Cast Metal Bars, &c.

Description.	Percentage of Combined Carbon.	WATERS, ETC., IN WHICH THE BARS WERE IMMERSED.											
		SEA-WATER.						AN ACID COLLIERY WATER.					
		Zinc Rod forming one Element with each of following.		Wrought-Iron Bar forming one Element with each of following.		Iron Scale (Magnetic Oxide) forming one Element with each of following.		Zinc Rod forming one Element with each of following.		Wrought-Iron Bar forming one Element with each of following.		Iron Scale (Magnetic Oxide) forming one Element with each of following.	
		Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.	Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.	Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.	Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.	Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.	Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.
Soft Siemens-Martin steel,	...	6·17	N	0·52	P	1·25	P	5·55	N	0·23	N	1·05	P
Wrought iron,	Trace	2·80	N	...	...	2·62	P	2·77	N	...	...	1·06	P
Soft steel (Firths),	0·570	6·06	N	0·25	N	1·50	P	3·81	N	0·53	N	0·50	P
Bessemer steel,	0·550	6·40	N	0·25	N	1·20	P	3·91	N	0·53	N	0·34	P
Puddled steel,	0·440	4·25	N	0·34	N	0·25	P	3·28	N	0·75	N	0·25	P
Puddled steel (chilled),	0·490	7·91	N	0·77	N	0·81	P	4·00	N	0·81	N	0·25	P
Hard steel (Firth's),	1·600	6·93	N	0·96	N	0·87	P	3·88	N	0·72	N	0·24	P
Cast metal (containing graphitic carbon, 2·40),	1·000	10·28	N	0·50	P	1·06	P	4·00	N	1·00	N	0·18	P
Tungsten steel,	1·750	2·72	N	0·47	P	...	...	3·15	N	0·17 0·22	P then N after	...	...

REMARKS.

The results show the relative galvanic action expressed in degrees of deflection of the galvanometer.

The zinc rod was the same diameter as the iron and steel bars.

The iron scale was an irregular-shaped piece; but was employed in all the above experiments, so that for purposes of comparison the results are correct.

Each result is the average of 10 observations made in each case in the same manner for exact comparison.

The chemical composition and history of this acid colliery water is contained in a paper by the author, entitled "Some curious Concretion Balls derived from a Colliery Water," read before the British Association, Section B., Chemical Science, August 1, 1879.

TABLE E.

Galvanometer Experiments with Bright Steel, Wrought Iron, Cast Metal Bars, &c.

Description.	Percentage of Combined Carbon.	WATERS, ETC., IN WHICH THE BARS WERE IMMERSED.											
		RIVER DON WATER.						DISTILLED WATER.					
		Zinc Rod forming one Element with each of following.		Wrought Iron Bar forming one Element with each of following.		Iron Scale (Magnetic Oxide) forming one Element with each of following.		Zinc Rod forming one Element with each of following.		Wrought Iron Bar forming one Element with each of following.		Iron Scale (Magnetic Oxide) forming one Element with each of following.	
		Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.	Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.	Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.	Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.	Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.	Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.
Soft Siemens-Martin steel, . .	...	1·75	N	Slight deflection.	P	Slight deflection.	P	Slight deflection.	N	No perceptible movement.	...	Slight deflection.	P
Wrought iron, ...	Trace	1·00	N	...	...	,,	P	,,	N		...	,,	P
Soft steel (Firth's), . . .	0·570	0·84	N	,,	N	,,	P	,,	N		...	,,	P
Bessemer steel, ...	0·55	0·92	N	,,	N	,,	P	,,	N		...	,,	P
Puddled steel, ...	0·44	0·88	N	,,	N	,,	P	,,	N		...	,,	P
Puddled steel (chilled), . . .	0·49	1·08	N	,,	N	,,	P	,,	N		...	,,	P
Hard steel (Firth's), ...	1·60	0·97	N	,,	N	,,	P	,,	N		...	,,	P
Cast metal (graphitic carbon, 2·40), .	1·00	1·00	N	,,	N	,,	P	,,	N		...	,,	P
Tungsten steel, ...	1·75	1·42	N	,,	...	,,	P	,,	N		...	,,	P

REMARKS.

The chemical composition and history of this river water is contained in a paper by the author, entitled "Variations in the Composition of River Waters," read before the Chemical Society of London, December 1875.

Each result in the above Table is the average of ten observations.

TABLE F.

Galvanometer Experiments with Bright Steel, Wrought Iron, Cast Metal Bars, &c.

Description.	Percentage of Combined Carbon.	SOLUTION IN WHICH THE BARS WERE IMMERSED. One-Fifth Normal Standard Sulphuric Acid.					
		Zinc Rod forming one Element with each of following.		Wrought Iron Bar forming one Element with each of following.		Iron Scale (Magnetic Oxide) forming one Element with each of following.	
		Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.	Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.	Deflection of Galvanometer in Degrees.	Electro-Chemical Position of the Metals.
Soft Siemens-Martin steel, . .	...	8·90	N	0·62	P	14·15	P
Wrought iron, ...	Trace	10·10	N	...	...	14·90	P
Soft steel (Firth's), ...	0·570	8·89	N	0·25	N	14·87	P
Bessemer steel, ...	0·55	9·03	N	0·55	N	13·80	P
Puddled steel, ...	0·44	8·08	N	0·60	N	13·90	P
Puddled steel (chilled), . . .	0·49	9·97	N	0·90	N	13·77	P
Hard steel (Firth's), ...	1·600	8·84	N	0·57	N	14·95	P
Cast metal (graphitic carbon, 2·40 per cent.), ...	1·00	12·50	N	0·95	N	15·07	P
Tungsten steel, ...	1·75	9·40	N	0·16	N	14·27	P

REMARKS.

Each result is the average of ten observations made in the same manner for exact comparison.

A reference to the analyses of the steel plates shows that, as regards manufacture, they were selected from three of the most important classes of steel, viz., Bessemer, Siemens-Martin, and cast steel, and a sample of the softest and hardest temper was taken from each kind.

TABLE G.

Galvanometer Experiments with Bright Steel, Wrought Iron, and Cast Metal Plates, &c.

Description.	Percentage of Combined Carbon.	WATERS IN WHICH THE PLATES WERE IMMERSED. — SEA-WATER. Wrought Iron Plates (*Bright*) forming one Element with each of the following Bright Steel, &c. Plates. — Deflection of Galvanometer in Degrees. Average.	Highest.	Electro-Chemical Position of the Metals.	Plates covered with Scale (Magnetic Oxide) placed in Galvanic connection with *Bright* Plates from the same Piece of Steel, &c. — Deflection of Galvanometer in Degrees. Average.	Highest.	Electro-Chemical Position of the Metals.
Soft Siemens-Martin steel, . .	0·170	2·69	3·00	N	3·51	4·00	P
Soft steel (Firth's), ...	0·46	1·25 0·77	1·50 2·25	N for 3 minutes, afterwards P to end of Experiment	3·27	3·75	P
Wrought iron, ...	Trace	...	...	...	2·92	3·00	P
Soft Bessemer, ...	0·150	0·37 0·83 0·28	0·50 2·75 0·50	N for 3 minutes P for 120 „ N afterwards	3·96	5·00	P
Hard Bessemer, ...	0·510	1·05 0·75	1·50 1·25	N for 20 minutes P afterwards	3·27	4·25	P
Hard Siemens-Martin steel, . .	0·720	1·25 0·14 0·15	1·50 0·25 0·50	N for 10 minutes P for 85 „ N afterwards	2·58	3·75	P
Hard steel (Firth's)	1·407	1·06 0·21 0 12	1·75 0·50 0·15	N for 15 minutes P for 80 „ N for 55 „	1·63	3·75	P
Cast metal,*	2·010	1·50 †	2·00	P	0·93 0·47 ‡	2·75 0·60	N for 30 minutes P afterwards

* Graphitic carbon, 1·50.

REMARKS.

† Each result is the average of about thirty observations which were taken at regular intervals extending over three hours.

‡ Each result is the average of twenty-three observations taken in each case at equal distances of time, each experiment extending over two hours.

TABLE H.

Galvanometer Experiments with Copper, Steel, Wrought Iron, and Cast-Metal Plates, &c.

Description	Percentage of Combined Carbon.	WATER IN WHICH THE PLATES WERE IMMERSED. SEA-WATER. Copper Plate (*Bright*), forming one Element with each of the following Bright Steel, &c., Plates.			
		Deflection of Galvanometer in Degrees.			Electro-Chemical Position of the Metals.
		Average.	Highest.	Lowest.	
Soft Siemens-Martin steel, . .	0·170	6·17	9·50	4·50	P
Soft steel (Firth's), ...	0·460	6·15	9·00	4·25	P
Wrought iron, ...	Trace	8·62	9·75	4·50	P
Soft Bessemer, ...	0·150	6·74	9·50	5·25	P
Hard Bessemer, ...	0·510	7·33	9·75	5·40	P
Hard Siemens-Martin steel, . .	0·720	7·25	9·50	5·75	P
Hard steel (Firth's), ...	1·407	7·05	8·60	5·50	P
Cast metal,*	2·010	7·26	10·50	5·75	P

* Graphitic carbon, 1·50 per cent.

REMARKS.

Each of the above results is the average of nineteen observations, each taken at equal distances of time, each experiment extending over three hours.

TABLE I.

Galvanometer Experiments with Bright Steel, Wrought Iron, and Cast-Metal Plates, &c.

Description.	Percentage of Combined Carbon.	SOLUTION IN WHICH THE PLATES WERE IMMERSED. One-Fifth Normal Standard Sulphuric Acid. Wrought-Iron Plates (*Bright*), forming one Element with each of the following Bright Steel, &c., Plates. Deflection of Galvanometer in Degrees. Average.	Highest.	Electro-Chemical Position of the Metals.	Plates covered with Scale (Magnetic Oxide) placed in Galvanic Connection with *Bright* Plates from the same piece of Steel, &c. Deflection of Galvanometer in Degrees. Average.	Highest.	Electro-Chemical Position of the Metals.
Soft Siemens-Martin steel,	0·170	0· 7 0.0	2·25 1·00	P for 26 minutes N afterwards			
Soft steel (Firth's),	0·460	0·25 1·00	0·25 1·25	P for 2 minutes N afterwards			
Wrought iron,	Trace						
Soft Bessemer,	0·150	0·40 0·24	2·00 0·25	P for 60 minutes N for 120 „			
Hard Bessemer,	0·510	1·21	1·75	P			
Hard Siemens-Martin steel,	0·720	1·62	2·00	P			
Hard steel (Firth's),	1·407	0·74	2·00	P			
Cast metal,*	2·010	0·44 0·63	1·25 0·90	P for 12 minutes N afterwards	0·62 0·12	1·00 0·25	P for 5 minutes N afterwards

* Graphitic carbon, 1·50 per cent.

REMARKS.

Each result is the average of about forty observations, taken at equal distances of time, each experiment extending over three hours.

It is interesting to compare the results of the above table and diagram I with table and diagram G. A partial reversal of the galvanic positions of some of the steels appears to take place, when an acidsolution is employed instead of sea-water, as previously pointed out.

Experiments to ascertain the Galvanic Action caused by Plates of Wrought Iron (the half of every Plate being Bright, the other half left with its Scale on).

Eleven plates of wrought-iron (cut from the same large plate) were each bent double, thus, the half of every plate polished bright, and the other half left covered with scale just as it left the rolls, they were then placed in a clean porous cell, Daniells battery, filled with sea-water.



Fig. 2.

Each plate was 4·12 inches square, and as there were eleven in the whole series, this represents a total superficial area of 373·48 sq. inches of scaled surface, and 373·48 sq. inches of bright surface, though, of course, the action of a voltaic series like this would be different to

that of two large plates of such superficial area. This arrangement, however, illustrates intensified galvanic action.

The whole were arranged in a voltaic series, as shown in sketch—

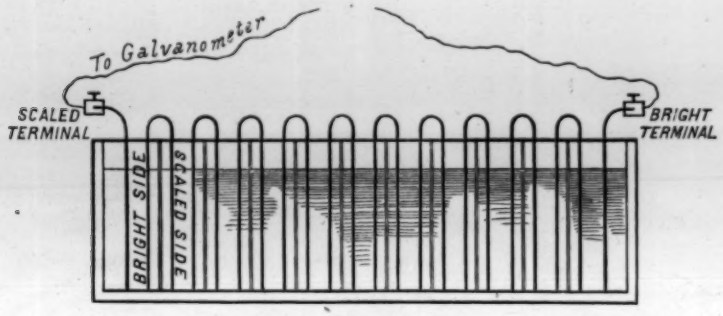


Fig. 3.

and attached to the terminals of a galvanometer, the deflections were as recorded under

TABLE J.

Time of Observation	Deflection in Degrees.	Electro-Chemical Position of Bright Part.
June 3rd, 7.35	17·00	Positive.
„ 7.40	14·00	„
„ 7.50	11·00	„
„ 8.0	9·00	„
„ 8.10	7·50	„
„ 8.20	6·75	„
„ 8.30	6·00	„
„ 8.40	5·00	„
„ 8.50	4·75	„
„ 9.0	4·50	„
„ 9.10	4·00	„
„ 9.20	3·75	„
„ 9.30	3·50	„
„ 9.40	3·25	„
„ 9.50	3·25	„
„ 10.0	3·00	„
„ 10.10	3·00	„
„ 10.20	2·75	„
„ 10.30	2·50	„
„ 10 35	2·50	„
June 4th, —	1·00	„
„ 5th, —	1·00	„
„ 6th, —	0·75	„

The galvanic mischief induced by iron scale is a matter of such importance that special attention has been directed to the measurement of this, as will be seen in these experiments (see Tables).

Experiments on the Galvanic Action set up by a series of Bars of Wrought Iron and various Steels immersed in Sea-Water.

The sample bars were portions cut from the same rods whose composition and general properties have been previously described.

The deflections of the needle of the galvanometer are shown in the accompanying tables K and L.

TABLE K.

Deflection of the Galvanometer Needle, produced when Bars of Wrought Iron *and* Hard Cast Steel (*all of the same size and polished bright*) *were immersed in Sea-Water forming the elements of Galvanic Action. Average of eight Experiments in each case.*

	Deflection of Needle.
3 Bars of wrought iron connected with 3 Bars of hard cast steel,	1·28 degrees
4 „ „ „ 4 „ „	1·38 „
5 „ „ „ 5 „ „	1·52 „
6 „ „ „ 6 „ „	1·75 „
7 „ „ „ 7 „ „	2·12 „
8 „ „ „ 8 „ „	2·25 „

The wrought iron was the electro-positive metal.

TABLE L.

Deflections of the Galvanometer Needle produced when Polished Bars of the Wrought Iron *and the* Soft Steel, *the same size, were immersed in Sea-Water forming the elements of Galvanic Action. Average of six Experiments in each case.*

	Deflection of Needle.
3 Bars of the *wrought iron* connected with 3 Bars of the *soft cast steel*,	1·00 degrees
4 „ „ „ 4 „ „	1·30 „
5 „ „ „ 5 „ „	1·33 „

The wrought iron was the electro-positive metal.

The whole of the preceding galvanometer experiments afford some comparison of the galvanic action set up by the exposure of combinations of wrought iron, steel, &c., to sea-water, colliery mineral waters, or river waters, &c., of known composition, and are so far interesting, because in actual practice wrought and cast iron and steel bars, plates, &c., are frequently exposed to similar destructive influences.

In experiments made by the author to ascertain the galvanic action taking place between wrought iron and steels, &c., over more extended periods of time, it was found that galvanic action between these metals had a tendency to be reduced from various causes during prolonged exposure to sea-water and other solutions.

The general deductions from the foregoing observations are that—

1st, The electro-chemical position of wrought-iron, steels, and cast metal appears capable of changing according to the nature of the solution in which they are immersed, an acid solution producing frequently different results from one containing only neutral salts. This interchange of electro-chemical position between the metals being also frequently observable both when immersed in an acid and neutral solution, as indicated by the preceding tables.

2nd, A measurable difference is noticeable in the behaviour of the various steels, &c. employed under the conditions recorded in the experiments. This would lead to the conclusion that the danger from the greatly increased corrosion in sea-water, &c, through galvanic action, is a factor not to be disregarded in compound structures of the preceding metals. The tendency to polarise each other's action, and the consequent interchange of electro-chemical position, would appear to exert a considerable influence in retarding and reducing this source of danger. Galvanic action between wrought iron and steels, &c., appears (from experiments on hand by the author) also to be materially reduced in course of extended periods of time, otherwise the liability to destructive corrosion through such action, though never inconsiderable, would be a more formidable matter to encounter than in engineering practice it really is. At the same time, it need scarce be remarked, this source of disintegration should not be overlooked in constructive works of wrought and cast iron and steel.

It is not now necessary for the author to attempt to enter into the further practical application of the results deducible from the experiments contained in this memoir; he has, however, great pleasure in being permitted the honour to present the results herein recorded as a contribution to the chemistry of iron and steel.

DIAGRAM D.

Illustrating some of the Comparative Results in Table D.

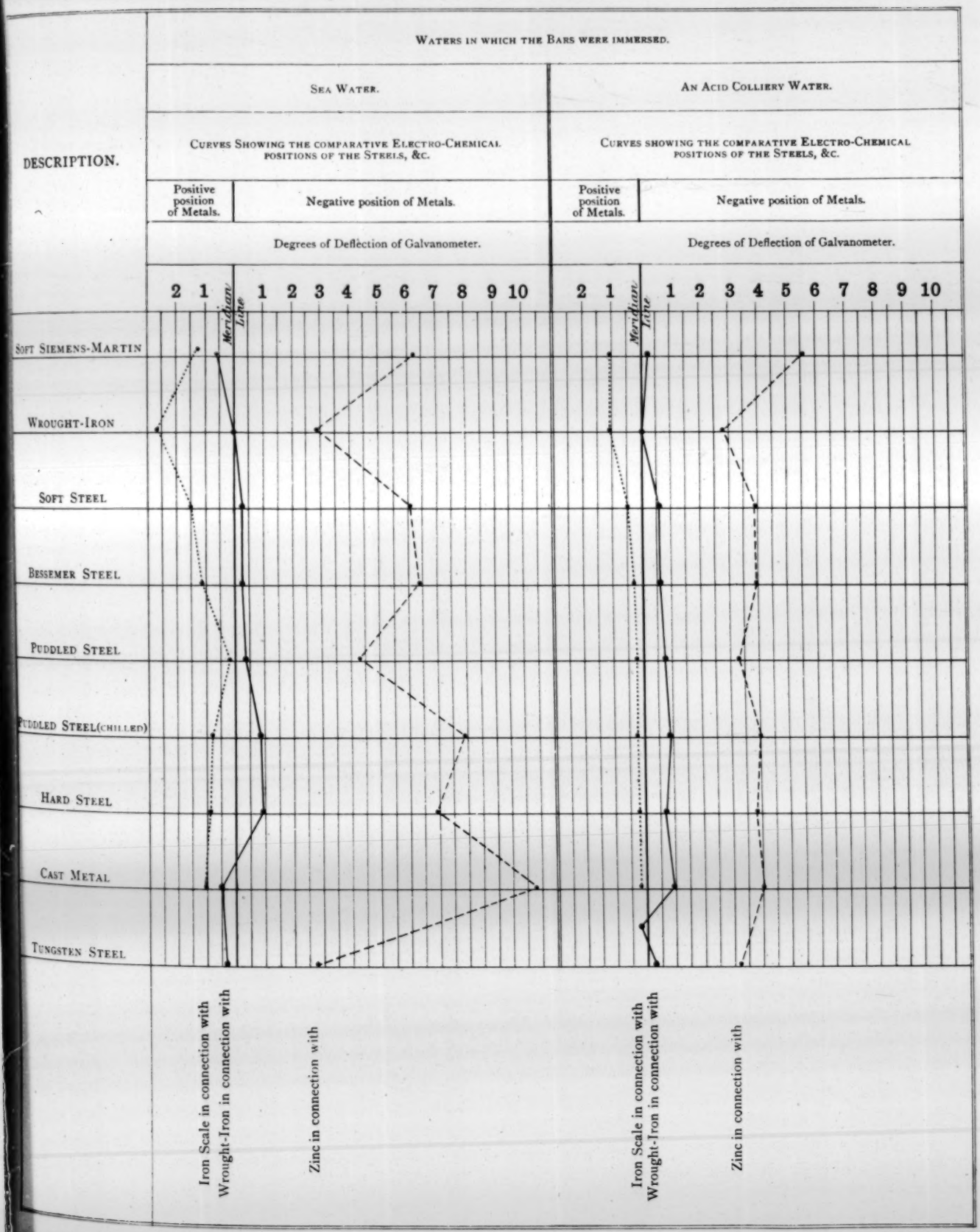
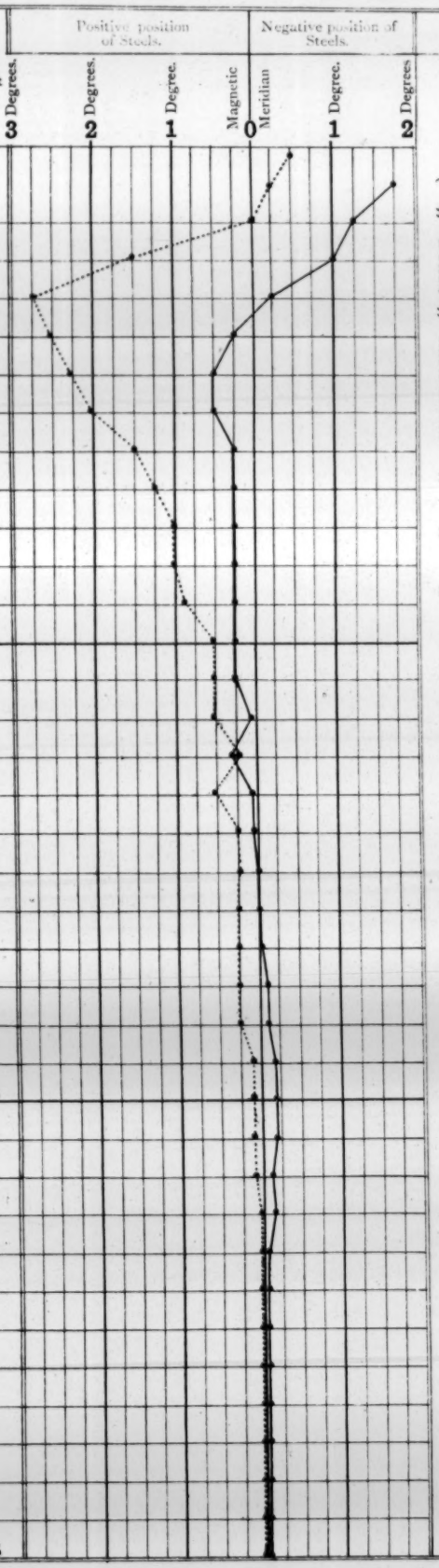


DIAGRAM G.

Illustrating the change of Electro-Chemical position between some Steel and Wrought-iron Plates, see Table G.

WATERS IN WHICH THE PLATES REMAINED CONSTANTLY IMMERSED DURING THE EXPERIMENT. SEA WATER.				CURVE SHOWING THE VARYING ELECTRO-CHEMICAL POSITION OF THE STEELS IN GALVANIC CONNECTION WITH WROUGHT-IRON.
Wrought-Iron Plate (bright) forming one element with a Hard Cast Steel Plate (bright).		Wrought-Iron Plate (bright) forming one element with a Soft Bessemer Plate (bright).		
Deflection of Galvanometer in Degrees at intervals of time during three hours.	Electro-Chemical position of the Hard Cast Steel.	Deflection of Galvanometer in Degrees at intervals of time during three hours.	Electro-Chemical position of the Soft Bessemer Steel.	Time from commencement of Experiment.
1·75	N	0·50	N	
		0·25	N	
1·25	N	0·00	ZERO	
1·00	N	1·50	P	
0·25	N	2·75	P	
0·25	P	2·50	P	
0·50	P	2·25	P	
0·50	P	2·00	P	
0·25	P	1·50	P	
0·25	P	1·25	P	
0·25	P	1·00	P	
0·25	P	1·00	P	
0·25	P	0·90	P	
0·25	P	0·50	P	1 HOUR
0·25	P	0·50	P	
0·10	P	0·50	P	
0·25	P	0·25	P	
0·10	P	0·50	P	
0·10	P	0·25	P	
0·00	ZERO	0·25	P	
0·00	"	0·25	P	
0·00	"	0·25	P	
0·10	N	0·25	P	
0·10	N	0·25	P	
0·15	N	0·10	P	
0·15	N	0·10	P	2 HOURS
0·15	N	0·10	P	
0·10	N	0·10	P	
0·10	N	0·00	ZERO	
0·00	ZERO	0·00	"	
0·00	"	0·00	"	
0·00	"	0·00	"	
0·00	"	0·00	"	
0·00	"	0·00	"	
0·00	"	0·00	"	
0·00	"	0·00	"	
0·00	"	0·00	"	3 HOURS



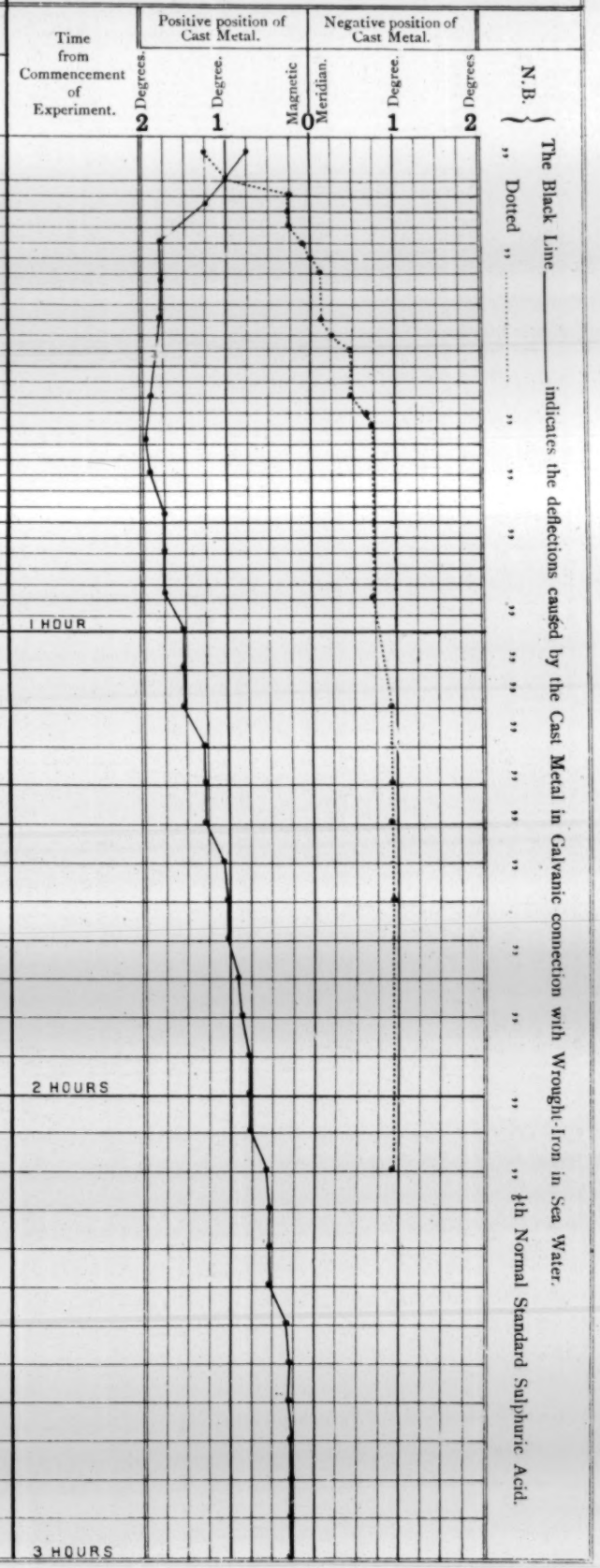
N.B. { The Black Line _____ indicates the deflections caused by the Hard Cast Steel in Galvanic connection with Wrought-Iron in Sea Water.
" Dotted " ..... " " " Soft Bessemer " " " "

DIAGRAM G. I.

Illustrating the change of Electro-Chemical position between Cast Metal and Wrought-Iron Plates, see Table G I.

SOLUTIONS IN WHICH THE PLATES REMAINED CONSTANTLY IMMERSED DURING THE EXPERIMENT.			
SEA WATER.		$\frac{1}{8}$th NORMAL STANDARD SULPHURIC ACID.	
Wrought-Iron Plate (bright) forming one element with a Cast Metal Plate (bright).		Wrought-Iron Plate (bright) forming one element with a Cast Metal Plate (bright).	
Deflection of Galvanometer in Degrees at intervals of time during three hours.	Electro-Chemical position of the Cast Metal.	Deflection of Galvanometer in Degrees at intervals of time during three hours.	Electro-Chemical position of the Cast Metal.
0·75	P	1·25	P
		1·00	P
1·25	P	0·25	P
		0·25	P
1·75	P	0·25	P
		0·10	P
		0·00	ZERO
1·75	P	0·10	N
		0·10	N
1·75	P	0·10	N
		0·10	N
		0·25	N
1·65	P	0·50	N
		0·50	N
		0·50	N
1·90	P	0·50	N
		0·60	N
2·00	P	0·75	N
		0·75	N
		0·75	N
1·90	P	0·75	N
		0·75	N
1·75	P	0·75	N
		0·75	N
1·75	P	0·75	N
		0·75	N
1·75	P	0·75	N
		0·75	N
		0·75	N
1·50	P	0·75	N
1·50	P		
1·50	P	0·90	N
1·25	P		
1·25	P	0·90	N
1·25	P	0·90	N
1·10	P		
1·00	P	0·90	N
1·00	P		
0·90	P		
0·65	P		
0·75	P		
0·75	P		
0·75	P		
0·60	P	0·90	N
0·50	P		
0·50	P		
0·50	P		
0·35	P		
0·30	P		
0·30	P		
0·25	P		
0·25	P		
0·25	P		
0·25	P		

CURVE SHOWING THE VARYING ELECTRO-CHEMICAL POSITION OF THE CAST METAL IN GALVANIC CONNECTION WITH WROUGHT-IRON.



N.B. The Black Line _____ indicates the deflections caused by the Cast Metal in Galvanic connection with Wrought-Iron in Sea Water.

" Dotted " ..... " " "

DIAGRAM H.

Illustrating the change of Electro-Chemical position between Steel, Wrought-Iron, and Copper Plates, see Table H.

WATER IN WHICH THE PLATES REMAINED CONSTANTLY IMMERSED DURING THE EXPERIMENT.

SEA WATER.

Copper Plate (bright) forming one element with a Soft Siemens-Martin Steel Plate.		Copper Plate (bright) forming one element with a Wrought Iron Plate (bright).		Time from Commencement of Experiment.
Deflection of Galvanometer in Degrees at intervals of time during three hours.	Electro-Chemical position of the Soft Siemens-Martin Steel.	Deflection of Galvanometer in Degrees at intervals of time during three hours.	Electro-Chemical position of the Wrought Iron.	
6·00	P	4·50	P	
7·00	P	9·00	P	
9·50	P	9·10	P	
9·25	P	9·50	P	
8·25	P	9·75	P	
7·25	P	9·75	P	
7·00	P	9·50	P	1 HOUR
6·25	P	9·50	P	
6·00	P	9·25	P	
5·75	P	9·00	P	
5·50	P	8·75	P	
5·25	P	8·50	P	
5·00	P	8·25	P	2 HOURS
5·00	P	8·00	P	
5·00	P	7·75	P	
5·00	P	7·75	P	
4·90	P			
4·75	P			
4·50	P			3 HOURS

CURVE SHOWING THE VARYING ELECTRO-CHEMICAL POSITION OF THE STEELS IN GALVANIC CONNECTION WITH COPPER PLATES.



N.B. { The Black Line _____ indicates the deflections caused by the Soft Siemens-Martin Steel in Galvanic connection with Copper in Sea Water.
" Dotted " ..... " " " Wrought-Iron " " " "

DIAGRAM 1.

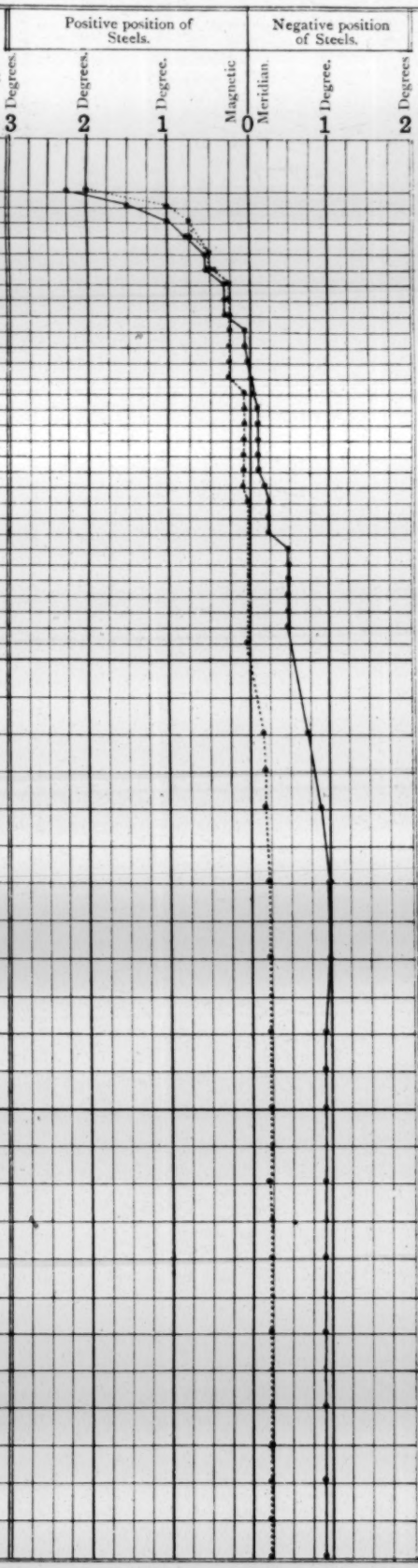
Illustrating the change of Electro-Chemical position between some Steel and Wrought-Iron Plates, see Table I.

Solution in which the Plates remained constantly immersed during the experiment.

$\frac{1}{8}$th Normal Standard Sulphuric Acid.

Wrought-Iron Plate (bright) forming one element with a Soft Siemens-Martin Steel Plate		Wrought-Iron Plate (bright) forming one element with a Soft Bessemer Plate (bright)		Time from commencement of Experiment.
Deflection of Galvanometer in Degrees at intervals of time during three hours.	Electro-Chemical position of the Soft Siemens-Martin Steel.	Deflection of Galvanometer in Degrees at intervals of time during three hours.	Electro-Chemical position of the Soft Bessemer.	
2·25	P	2·00	P	
1·50	P	1·00	P	
1·00	P	0·75	P	
0·75	P	0·75	P	
0·50	P	0·50	P	
0·50	P	0·50	P	
0·25	P	0·25	P	
0·25	P	0·25	P	
0·25	P	0·25	P	
0·10	P	0·25	P	
0·10	P	0·25	P	
0·00	ZERO	0·25	P	
0·00	"	0·25	P	
0·00	"	0·10	P	
0·10	N	0·10	P	
0·10	N	0·10	P	
0·10	N	0·10	P	
0·10	N	0·10	P	
0·10	N	0·10	P	
0·15	N	0·10	P	
0·25	N	0·00	ZERO	
0·25	N	0·00	"	
0·25	N	0·00	"	
0·50	N	0·00	"	
0·50	N	0·00	"	
0·50	N	0·00	"	
0·50	N	0·00	"	
0·50	N	0·00	"	
		0·00	"	1 Hour
0·75	N	0·15	N	
0·90	N	0·15	N	
1·00	N	0·25	N	
1·00	N	0·25	N	
0·90	N	0·25	N	
0·90	N	0·25	N	2 Hours
0·90	N	0·25	N	
0·90	N	0·25	N	
0·90	N	0·25	N	
0·90	N	0·25	N	
0·90	N	0·25	N	
0·90	N	0·25	N	3 Hours

Curve showing the varying Electro-Chemical position of the Steels in Galvanic connection with Wrought-Iron.



N.B. { The Black Line ——— indicates the deflections caused by the Soft Siemens-Martin Steel in Galvanic connection with Wrought-Iron in $\frac{1}{8}$th Normal Standard Sulphuric Acid.
" Dotted ..... " " "

XIII.—*Report upon the* Tunicata *dredged during the Cruises of H.M.SS. "Porcupine" and "Lightning," in the Summers of* 1868, 1869, *and* 1870.

By W. A. Herdman, D.Sc., Professor of Natural History in University College, Liverpool. (Plates XXXV. and XXXVI.)

(Read 7th January 1884.)

A few years ago the late Sir C. Wyville Thomson gave me for examination some specimens of Ascidians which had been obtained during the cruises of the "Porcupine" and "Lightning," and last summer I received from Mr John Murray the remainder of the Ascidiæ Simplices and two species of the Ascidiæ Compositæ from the same deep-sea dredging expeditions.* Some additional specimens of the "Porcupine" Ascidiæ Compositæ have been placed in my hands during the last few days (January 1, 1884). The present paper contains a detailed account of the Simple Ascidians alone; the Compound forms will be worked up along with the "Challenger" Ascidiæ Compositæ, and will be described and figured in the second part of my Report upon the *Tunicata* of the "Challenger" Expedition. It may, however, be useful to state here that the "Porcupine" Compound Ascidians include:—

Distaplia rosea, Della Valle.
One colony from Tangier Bay; 35 fathoms.

Aplidium fallax, Johnston.
Two small colonies from Loch Foyle; 10 fathoms.

Leptoclinum, sp.
One colony from Station 12 ("Lightning," 1868, Færöe channel); 530 fathoms.

Leptoclinum, sp.
Several colonies; locality unknown.

Leptoclinum albidum.
Several colonies from Tangier Bay; 35 fathoms.

* In the summer of 1868 H.M.S. "Lightning" explored the region of the North Atlantic lying between the Hebrides and the Færöes. In 1869 H.M.S. "Porcupine" made three cruises, the first off the north-west and west coasts of Ireland, the second off the south and south-west of Ireland, and the third off the north of Scotland as far as the Færöes. In 1870 the "Porcupine" dredged down the west coasts of France and Spain and in the neighbourhood of Gibraltar Strait, and explored the African coast of the Mediterranean as far east as Sicily.

BRITISH MUSEUM

Leptoclinum, n. sp.

One colony from Tangier Bay; 35 fathoms.

Didemnum, sp.

One colony from Station 54 (Færöe channel, "cold area"); 363 fathoms.

Botryllus, sp.

One colony from Tangier Bay; 35 fathoms.

Botryllus, sp.

One colony from Station 54 (Færöe channel, "cold area"); 363 fathoms.

Some of these possess an interest, apart from their morphological peculiarities, on account of the considerable depths from which they were obtained.

ASCIDIÆ SIMPLICES.

Family Ascidiidæ.

This family is represented in the collection by three species of *Ascidia*. The common *Ciona intestinalis* was apparently not dredged at any of the localities visited.

Ascidia scabra, O. F. Müller.

About thirty specimens of this well-known species, most of them attached to Lamellibranch valves, were dredged in Lough Foyle, Ireland, from a depth of 10 fathoms, during the first cruise of the "Porcupine" in 1869. Most of them are small. They range from 5 mm. to 25 mm. in greatest length. The shape varies considerably. The small individuals are ovate and much flattened; the larger ones are usually irregularly orbicular, but a few are oblong, and resemble the typical form of *Ascidia virginea*. The mantle is strong, and the muscle bands run very irregularly.

In some remarks upon this species published in 1880, I showed how variable the branchial sac might be in the arrangement of the stigmata.* The "Porcupine" specimens exhibit this irregularity, and, in addition, show in some places an imperfect development of the internal longitudinal bars, which is frequently observed in *Corella parallelogramma*, and which I have figured in *Ascidia triangularis*.† In 1880 I described the meshes in *Ascidia scabra*

* "Notes on British Tunicata," *Journ. Linn. Soc. Zool.*, vol. xv. No. 85, p. 274.

† *Loc. cit.*, pl. xvi. fig. 6.

as being usually transversely elongated, and as containing each about twelve stigmata; but in some of the "Porcupine" specimens the meshes are occasionally square, and have only 6–7 stigmata. Here and there at the angles of the meshes very short hemispherical papillæ may be found on the internal longitudinal bars, otherwise the "Porcupine" specimens agree with the description and figure in the *Journal of the Linnean Society.*

The large tentacles are rather stouter than those in my former figure,* but the arrangement is the same. The dorsal tubercle is somewhat variable in this species, but is always very simple. Two of the "Porcupine" specimens have it intermediate in shape between those figured by myself in 1880† and by JULIN‡ in 1881.

In several of the specimens large masses of ova are present in the peribranchial chamber.

Ascidia plebeia, Alder, var. nov. (?) (Plate XXXV. figs. 1–3).

External Appearance.—The body is irregularly ovate or pyriform, greatly compressed laterally, and attached by the posterior half, or more, of the left side. The anterior end is narrow and produced, the posterior considerably wider. The dorsal and ventral edges are irregular, but nearly equally curved; both sides are flattened. The branchial aperture is terminal and prominent; the lobes are well marked. The atrial aperture is from one-third to half way down the dorsal edge, prominent, projects laterally, and has well-marked lobes.

The surface is somewhat irregular, but not rough. There are adhering sand and shell fragments at the posterior end and over part of the left side.

The colour is yellowish-grey.

Length of the body, 4·2 cm.; breadth, 1·9 cm.

The test is moderately thick and strong, of a firm gelatinous consistency, translucent, smooth, and glistening on the inner surface, and richly supplied with blood-vessels. The left side and posterior end are thickened and made stiff by the presence of many imbedded sand grains and fragments of shells.

The mantle is moderately strong. The musculature is well developed on the right side and the anterior end of the left, but is very slight over the visceral part of the body. The sphincters are fairly strong.

The branchial sac is slightly plicated longitudinally. The transverse vessels are all of the same size. The internal longitudinal bars are strong, and bear large curved and sometimes forked papillæ at the angles of the meshes, and smaller simple ones between. The meshes are slightly elongated vertically, and

* *Loc. cit.*, pl. xvii. fig. 2. † *Loc. cit.*, pl. xvii. fig. 1.

‡ "Recherches sur l'organisation des Ascidies Simples, &c.," *Archives de Biologie*, t. ii. fasc. 1, pl. iv. fig. 2.

contain each four to six stigmata. The horizontal membranes are slight; there are none between the smaller papillæ.

The dorsal lamina is slightly ribbed transversely, and has small denticulations on the free margin.

The tentacles are numerous, and so closely placed that their bases touch. There are 30 or 32 large, with about the same number of intermediate smaller ones.

The dorsal tubercle is small and simple, ovate in outline, and with the narrower end anterior. The aperture is anterior, with the right horn rather longer than the left, but neither of them curved. No peritubercular area is present.

Locality.—Two specimens, one large and one small, were obtained, during the second cruise of the "Porcupine," at Station 33, 20th July 1869, lat. 50° 38′ N., long. 9° 27′ W.; depth, 75 fathoms; bot. temp., 9°·8 C.

These specimens are exceedingly like the common *Ascidia plebeia*, Alder, but differ from it in some details. They have no trace of the greenish tinge so characteristic of *Ascidia plebeia* even after preservation in alcohol, and the test is firmer and stiffer. The general shape, however, and the positions of the apertures (see Pl. XXXV. fig. 1) recall the characters of *Ascidia plebeia*. The measurements in the above description are those of the larger specimen; the smaller one is 2·6 cm. in length and 1·4 cm. in breadth. In the smaller specimen the atrial aperture is not distant from the branchial, and is turned forwards.

The body, when the test is removed, is long and narrow, and the branchial sac extends slightly beyond the viscera posteriorly (see Pl. XXXV. fig. 2). The stomach is large and the intestine rather wide. It is covered with renal vesicles and the reproductive cæca. The ovary forms thick swollen masses, and the spermary small dendritic tubules scattered chiefly over the anterior part of the intestine. The oviduct and the vas deferens are both greatly distended in the larger specimen, and form conspicuous curved tubes on the left side of the body (see Pl. XXXV. fig. 2). Large quantities of ova were found in the peribranchial chamber.

The branchial sac resembles that of *Ascidia plebeia* in every particular.* The primary papillæ are large (Pl. XXXV. fig. 3), and in some cases bear pinnæ or small tubercles on the sides. Smaller transverse vessels connecting the intermediate or secondary papillæ appear never to be present.

The tentacles are numerous and closely placed, more closely than I have found before in *Ascidia plebeia*, and I can only distinguish two sizes, with an occasional very much smaller one here and there. The dorsal lamina is very slightly ridged and denticulated. The prebranchial zone is papillated all over,

* Compare description in *Journ. Linn. Soc. Zool.*, vol. xv. No. 85, p. 288.

and rather wide. There is no peritubercular area, and the dorsal tubercle is small and simple, just as in *Ascidia plebeia*. It only occupies about one-fourth of the breadth of the prebranchial zone.

After taking all the characters into consideration, I am inclined to refer the specimens to *Ascidia plebeia*, Alder, of which they may be considered as a variety until more is known about the range of variation in the species.

Ascidia, sp.

A torn test of a single individual of the genus *Ascidia* was found adhering to some fragments of Annelide tubes dredged at Station 45, lat. 35° 36′, long. 2° 29′; "Porcupine" 1870; depth, 207 fathoms; bot. temp., 12°·4 C.

As the test only is present, it is, of course, impossible to identify the species, but there can be no doubt as to the genus. I consider it worthy of record simply on account of the depth from which it was obtained.

Family CYNTHIIDÆ.

No members of the sub-families CYNTHINÆ and BOLTENINÆ are in the collection, but the STYELINÆ are represented by the common *Styela grossularia*, van Beneden, and four species of *Polycarpa*, three of which appear to be undescribed. One of these is from the Mediterranean, one from the Færöe channel, and the other from the North Atlantic S.W. of Ireland, and from outside the Strait of Gibraltar, in rather deep water.

Styela grossularia, van Beneden.

A large number of small individuals of this species were found attached to specimens of *Polycarpa pomaria*, dredged near Belfast on 4th August 1869, at a depth of 70 fathoms.

They vary from 2 mm. to 3 mm. in greatest length. Although they are so small, all of those I have examined are sexually mature and contain ripe ova, and in some cases tailed larvæ, in the peribranchial cavity.

Also half a dozen small specimens of this species were found on a fragment of shell from Station 54, lat. 59° 56′ N., long. 6° 27′ W., during the third cruise of the "Porcupine" in 1869; depth, 363 fathoms; bot. temp.—0°·3 C.

They are of the blister-like form, flattened antero-posteriorly, and with expanded margins. So far as I am aware, this is the greatest depth at which *Styela grossularia* has been obtained. It is usually regarded as a shallow water species, and in some localities extends up between tide marks further than any other species of Tunicate.

There are also in the collection one large and six small specimens, labelled "'Lightning,' off Valentia."

Polycarpa pusilla, n. sp. (Plate XXXV. figs. 4–6).

External Appearance.—The body is spherical, ellipsoidal, ovate, or pyriform, is not compressed, and is unattached. The anterior end is narrower if not the same as the posterior, which is wide and rounded. When the shape is ellipsoidal, the long axis is dorso-ventral. The apertures are not distant, on the anterior end; in some cases prominent, in others sessile and inconspicuous; no lobes are visible.

The surface is even, but completely covered by an incrusting layer of fine sand. Hair-like processes are present on the posterior half or so of the body, and bear sand grains.

The colour is light brown.

Length of body (in an average sized specimen), 5 mm.; breadth, 6 mm.; thickness, 4 mm.

The test is moderately thick and tough, completely concealed externally by the sand, and smooth internally, it is continued posteriorly into the hair-like processes bearing sand grains.

The mantle is rather strong. The muscle bands are numerous, though fine, and form a close network. Most of them compose a strong longitudinal layer internally, and a weaker circular layer externally. The sphincters are well developed.

The branchial sac has four folds upon each side. The internal longitudinal bars are very broad, ribbon-like membranes; there are four or five on each fold, and one or two in the interspace. The meshes are rather large and square, and contain each five or six stigmata. In the mature sac the stigmata are long and narrow, and each mesh is divided transversely by a narrow horizontal membrane.

The tentacles are of two sizes, with occasional smaller ones between. There are usually upwards of fifty altogether in the circle.

The dorsal lamina is a narrow membrane with slight transverse ribs, which begin a short way from the anterior end. The edge is thickened, but has no denticulations.

The dorsal tubercle is simple, and ovate in outline; the aperture is directed anteriorly and to the left. The horns are not coiled, but almost touch; the long axis is vertical.

Locality.—Thirty-five specimens of this species were obtained 40 miles off Valentia, at a depth of 110 fathoms in the North Atlantic; and one specimen was obtained at Station 31, "Porcupine" 1870, lat. 35° 56′ N., long. 7° 6′ W., at a depth of 477 fathoms; bot. temp., 10°·3 C.

This is a curious little species, in external appearance bearing considerable resemblance to *Polycarpa pilella*, a species discovered during the "Challenger" Expedition at Bahia, in shallow water. The present species is usually spherical,

and most of the specimens look like little rough bullets covered with sand (see Plate XXXV. fig. 4, e. and f.). They feel quite hard, the test being rather firm. The specimens collected vary from 2 mm. to 9 mm. in greatest diameter. Most of them are small. In the majority, the apertures are not visible externally, and it is impossible to distinguish the ends and sides without dissection. Ina few, however (see Plate XXXV. fig.4, a and b.), the apertures are prominent, terminating short conical projections from the anterior end of the body. No lobes are visible, but when the test is removed the apertures are seen to be distinctly cross-slit.

The mantle does not adhere to the test, and consequently the body can be readily shelled out. The musculature is well developed all over, and consists of two distinct layers, the internal longitudinal, starting anteriorly in bundles of fibres radiating from the apertures, and the external circular. Besides these, there are also a few oblique and irregularly running bundles.

The branchial sac appears variable. In small (young) specimens (see Plate XXXV. fig. 6), the stigmata are short and rounded, and the transverse vessels very wide; while in the larger specimen examined, the stigmata are long (see Plate XXXV. fig. 5) and closely placed, and the transverse vessels all very narrow. The internal longitudinal bars are wide and ribbon-like. In the part of the sac of the large specimen examined (see Plate XXXV. fig. 5) there were five bars on each of two folds next the endostyle, and only a single bar in the interspace, while the two rows of meshes formed by this bar with the adjacent folds had from five to six stigmata in each mesh. The series next to the endostyle was wider, each mesh containing nine or ten stigmata. In the young specimen examined and figured (Pl. XXXV. fig. 6) the first or dorsal fold (*br. f. I.*) has seven bars, and is separated by a single row of meshes from the dorsal lamina, and by four rows of meshes from the second fold—hence this interspace has three bars. The second fold (*br. f. II.*) has three bars, and is separated from the third by three rows of meshes, hence this, the second interspace, has two bars only. The third fold (*br. f. III.*) has five bars, and is separated from the fourth by three rows of meshes, hence this third interspace has also two bars. The fourth fold (*br. f. IV.*) has also five bars, and is separated from the endostyle by two rows of stigmata, or an interspace with one bar. The stigmata in this sac are all short and rounded, and placed far apart. There are usually three or four in a mesh.

The tentacles (Plate XXXV. fig. 6) are rather irregular. Three sizes are present, but members of the third order are often absent, as seen near the endostyle at the left hand end of the figure. The polycarps are fairly numerous. Some are male, others female, and others hermaphrodite. The endocarps are rare. The stomach is globular, and deeply sulcated.

Polycarpa curta, n. sp. (Pl. XXXVI. figs. 7–11).

External Appearance.—The body is ovate, ellipsoidal, or elongated transversely; not compressed laterally, and unattached. The anterior end is wide and convex, the posterior is usually still wider, and flat or irregular; the dorsal and ventral edges are short and similar. The apertures are rather far apart, being placed at the opposite extremities of the anterior end. They are equally anterior, and are sessile and inconspicuous. There are no apparent lobes.

The surface is smooth, and fairly regular, but is slightly incrusted with small sand grains.

The colour varies from yellowish-grey to light brown.

Greatest length of the body, dorso-ventrally (in an average specimen), 9 mm.; breadth (antero-posteriorly), 7 mm.; thickness, (laterally), 5 mm.

The test is thin, but very tough and leathery. It is quite opaque. The outer surface is slightly sandy, and the posterior end has a few hair-like prolongations, to which sand grains are attached.

The mantle does not adhere to the test. The apertures are slightly cross-slit, and the sphincters surrounding them are strong. The musculature elsewhere on the mantle is well developed, the muscle bands forming a close network not clearly divided into longitudinal and circular layers.

The branchial sac has four well-marked folds on each side. The most dorsally placed is larger than the others, and has about twelve internal longitudinal bars. The rest of the folds have about six bars each, and there are two bars in each interspace. All the internal longitudinal bars are flat, ribbon-like membranes of considerable width. The transverse vessels are all of the same size. The meshes are about square, and contain each four or five stigmata.

The dorsal lamina is a narrow membrane, with no ribs and no denticulations.

The tentacles are not very numerous. There are eighteen or twenty large tentacles, and the same number of smaller intermediate ones.

The dorsal tubercle is simple. It is fusiform in outline, with the long axis vertical. There is an irregular slit down the middle, but there is no curvature, hence no horns are present.

Locality.—Sixteen specimens of this species were dredged at Station 12; "Lightning," 1868; lat. 59° 36′ N., long. 7° 20′ W.; depth, 530 fathoms; bot. temp., 6°·4 C.

This species is allied to *Polycarpa pusilla*, but differs both in external appearance and in internal structure. It is not so much incrusted with sand, and the shape, though variable in both species, is here more decidedly elongated dorso-ventrally (Plate XXXVI. figs. 7 and 8), the result being the apertures come to be placed far apart at the opposite extremities of the wide anterior end (see Plate XXXVI. fig. 7). The greatest length is always dorso-ventrally, and this ranges in the specimens collected from 5 mm. to 13 mm.

The branchial sac has the folds (Plate XXXVI. fig. 9) better developed than in *Polycarpa pusilla*. In one sac examined the arrangement, starting from the dorsal lamina along the right hand side, was—one row of wide meshes containing 8 to 10 stigmata, then the 1st fold with 12 bars, then the 1st interspace with 2 bars, then the 2nd fold with 7 bars, then the 2nd interspace with 2 bars, then the 3rd fold with 7 bars, then the 3rd interspace with 3 bars, then the 4th fold with 6 bars, and then a row of wide meshes separating the ventral fold from the endostyle. Figure 10 on Plate XXXVI. shows the narrow dorsal lamina and the wide row of meshes separating it from the commencement of the first fold on the left side of the sac. A large number of fine muscle fibres are present in the branchial sac, chiefly in the transverse vessels.

The peritubercular area (Plate XXXVI. fig. 2) is large and triangular in shape. It is almost perfectly symmetrical. The tubercle is very different from that of *Polycarpa pusilla*. It is comparatively simple, since the slit, though irregular in shape, is not curved to form horns or spirals (see Plate XXXVI. fig. 11, *d. t.*). The polycarps are irregularly rounded; they are hermaphrodite. Endocarps are not numerous.

Polycarpa pomaria, Savigny.

Twelve moderately large specimens of this common species were dredged on August 4, 1869, near Belfast, at a depth of 70 fathoms. The largest individual measures 3 cm. in length and 2 cm. in breadth.

Three or four of the specimens differ somewhat in appearance from the rest; their tests are thinner and smoother, but otherwise they appear to be exactly the same.

A single individual of this species was also obtained in 1870 in Tangier Bay from a depth of 35 fathoms. The test is stiff, giving a solid appearance and feel to the specimen, and the exterior is somewhat incrusted with sand. The difference in external appearance between this individual and those with smooth thin tests from near Belfast is very considerable, but the species is a variable one, and intermediate forms are common.

Polycarpa formosa, n. sp. (Plate XXXVI. figs. 1–6).

External Appearance.—The body is elongated antero-posteriorly, and varies from pyriform to oblong in shape. There is almost no lateral compression, and attachment is by the posterior extremity. The anterior end is moderately wide, but narrower than the middle of the body. The posterior end is narrower than the anterior. The widest region is usually a little behind the middle of the body. The apertures are both anterior, and not distant. They form slight papillæ, and are each distinctly four-lobed.

The surface is even, but considerably incrusted with sand grains, especially

at the posterior end, where there are also root-like prolongations of the test, to which sand is attached.

The colour is light grey where the test is exposed; reddish-brown from the sand elsewhere.

Length of the body (average specimen), 1·5 cm.; breadth, ·7 cm.; length of the root-like appendages, 1 cm. to 2 cm.

The test is thin, but moderately tough. It is translucent where free from sand. The posterior end from which the sandy prolongations spring is somewhat thickened.

The mantle is rather slight. The muscle bands are feeble, and not very numerous; they form an open irregular network.

The branchial sac has four folds upon each side. Each fold is formed by the aggregation of from six to twelve internal longitudinal bars. There are two to four bars in each interspace. The transverse vessels are of two sizes, alternating regularly. The meshes are much elongated vertically, and contain about three or four stigmata each. The stigmata are long and narrow, and the meshes are divided transversely by a narrow horizontal membrane.

The dorsal lamina is rather wide, and has irregular and partial transverse ribs; the margin is smooth.

The tentacles are numerous, and closely placed. They are large, and all of much the same size.

The dorsal tubercle is a simple, slightly-curved band, with the extremities directed posteriorly.

Locality.—Six specimens were dredged in Tangier Bay, on the 5th August 1870, from a depth of 35 fathoms.

There is a characteristic appearance about the specimens of this species, although they all differ somewhat in shape (see Plate XXXVI. figs. 1–3). In all, the apertures are closely placed at the anterior end, the body is elongated antero-posteriorly, and the posterior end is prolonged into a mass of branched projections covered with sand. The dimensions of the six specimens are as follows:—

	A.	B.	C.	D.	E.	F.
Length of body alone, . .	2·0 cm.	1·5 cm.	1·5 cm.	1·6 cm.	1·0 cm.	1·4 cm.
Length of posterior projections,	1·1 cm.	0·7 cm.	2·2 cm.	1·0 cm.	1·4 cm.	2·5 cm.
Breadth of body, . . .	1·1 cm.	0·9 cm.	0·7 cm.	0·7 cm.	0·6 cm.	0·5 cm.

The folds in the branchial sac (Pl. XXXVI. fig. 5), although they have a con-

siderable number of internal longitudinal bars, do not project much into the cavity. The sac, as a whole, is very similar in structure to those of *Styela oblonga*, *S. flava* and *S. glans*.*

The dorsal tubercle is very simple, the prebranchial zone is narrow (Plate XXXVI. fig. 6), and the peritubercular area small, and not occupied by the tubercle. The tentacles are of considerable size, and have large bases.

Polycarps are not very numerous. They are scattered over the inner surface of the mantle (Plate XXXVI. fig. 4, *g.*). They are unisexual. The male polycarps are deeply cleft into lobes.

The alimentary canal lies on the dorsal part of the left side of the body. The stomach is pyriform, and is strongly ribbed externally; the intestinal loop is moderately open, and the rectum is long and narrow (see Plate XXXVI. fig. 4, *r.*).

Family Molgulidæ.

This family is represented in the collection by two species of *Molgula* and the common *Eugyra glutinans*.

Molgula, sp.

A single small specimen of a *Molgula*, slightly torn, was found adhering to one of the specimens of *Polycarpa pomaria* from near Belfast; 70 fathoms.

The shape is nearly globular; 8 mm. in diameter, and slightly compressed laterally. Short hair-like processes project all over, and have a few grains of sand and other foreign bodies attached to them, but there is no incrusting coat. The test is moderately thin, soft, and nearly transparent. The colour is light yellowish-grey. Possibly this may be *Molgula nana*, Kupffer.

Molgula ampulloides, van Beneden.

One specimen of this rather widely-diffused species was dredged in Lough Foyle, during the first cruise of the "Porcupine" in 1869, from a depth of 10 fathoms. It measures 1·7 cm. in length, and 1·4 cm. in greatest breadth.

Eugyra glutinans, Möller (Plate XXXVI. figs. 12–14).

Eighteen specimens of this common and apparently gregarious species were dredged in Donegal Bay, Ireland.

None of the specimens are large. They range from 4 mm. to 12 mm. in greatest diameter. The incrusting sand is very fine and comes off readily, the result being that most of the specimens have very little left, and in some the delicate test is almost completely exposed.

* See Report upon the Tunicata dredged during the voyage of H.M.S. "Challenger," Part I. Plate XX. figs. 4, 8, and 11.

In the branchial sacs of several of these specimens, the vessels forming the apices of the spiral infundibula are considerably swollen, attaining as much as twice their normal calibre (Plate XXXVI. figs. 12 and 13); and the epithelium on the edges of the corresponding stigmata is greatly thickened (see Plate XXXVI. fig. 14).

Postscript, *May* 30, 1884.—Since the above paper was written and the plates finished, I have received, through the kindness of Dr P. Herbert Carpenter, three specimens of an interesting and apparently undescribed Molgulid, which was dredged from a depth of 440 fathoms in the Færöe channel during the third cruise of the "Porcupine" in 1869. This species will be described and figured in the Report on the "Challenger" Tunicata, Part II.

EXPLANATION OF THE PLATES.

The following system of lettering has been adhered to in all the figures:—

at. Atrial aperture.
br. Branchial aperture.
br. f. Fold in the branchial sac.
d. l. Dorsal lamina.
d. t. Dorsal tubercle.
en. Endostyle.
g. Genital organ.
h. m. Horizontal membrane of the branchial sac.
i. l. Internal longitudinal bar of the branchial sac.
m. The mantle.
p., *p'.* Papillæ of the branchial sac.
p. p. The peripharyngeal bands.
r. The rectum.
sg. The stigmata of the branchial sac.
st. The stomach.
tn., *tn'.* The tentacles.
tr., *tr'.*, *tr''.* The transverse vessels of the branchial sac.
z. The prebranchial zone.

PLATE XXXV.

Figs. 1–3. *Ascidia plebeia*, Alder, var. nov.
Figs. 4–6, *Polycarpa pusilla*, n. sp.

Fig. 1. *Ascidia plebeia*, var., seen from right side; natural size.
Fig. 2. *Ascidia plebeia*, var., the test removed, body seen from the left side; natural size.

Fig. 3. Small part of the branchial sac of *Ascidia plebeia*, var., seen from the inside; magnified 50 diameters.

Fig. 4. a.—f. Six specimens of *Polycarpa pusilla*, n. sp.; natural size.

Fig. 5. Small part of the branchial sac of *Polycarpa pusilla*, seen from the inside; magnified 50 diameters.

Fig. 6. Right half of the anterior part of the branchial sac, showing also the tentacles, the endostyle, the dorsal tubercle, the prebranchial zone, &c.; magnified 50 diameters.

PLATE XXXVI.

Figs. 1–6. *Polycarpa formosa*, n. sp.
Figs. 7–11. *Polycarpa curta*, n. sp.
Figs. 12–14. *Eugyra glutinans*, Möller.

Fig. 1. *Polycarpa formosa*, from the right side; natural size.

Fig. 2. Another specimen of the same species.

Fig. 3. Group of one small and two large specimens of the same species; natural size.

Fig. 4. Specimen of *Polycarpa formosa*, dissected from the left side to show the alimentary canal, &c.; slightly enlarged.

Fig. 5. Small part of the branchial sac of *Polycarpa formosa*, seen from the inside; magnified 50 diameters.

Fig. 6. Dorsal tubercle, &c., of *Polycarpa formosa*; magnified 50 diameters.

Fig. 7. Specimen of *Polycarpa curta*; natural size. The arrows indicate the branchial (inhalent) and atrial (exhalent) apertures.

Fig. 8. Two other specimens of the same species.

Fig. 9. Small part of the branchial sac of *Polycarpa curta*, seen from the inside; magnified 50 diameters.

Fig. 10. Small part of the dorsal lamina and branchial sac of *Polycarpa curta*, from inside; magnified 50 diameters.

Fig. 11. Dorsal tubercle and peritubercular area of *Polycarpa curta*; magnified 50 diameters.

Fig. 12. Centre of a spiral from branchial sac of *Eugyra glutinans*; magnified 50 diameters.

Fig. 13. Centre of another spiral from the branchial sac of *Eugyra glutinans*; magnified 50 diameters.

Fig. 14. Another similar spiral from *Eugyra glutinans*; magnified 300 diameters.

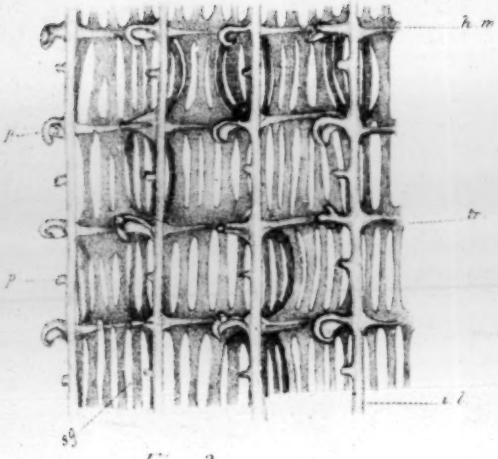


Fig. 3



Fig. 2.



Fig. 1.

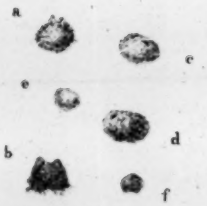


Fig. 4.

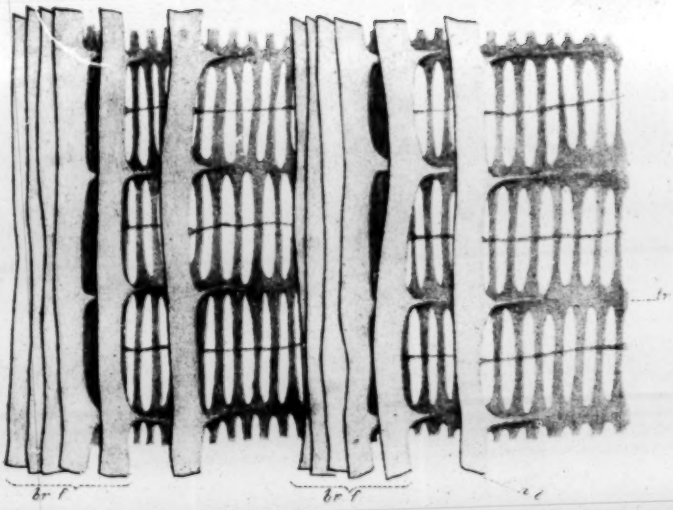
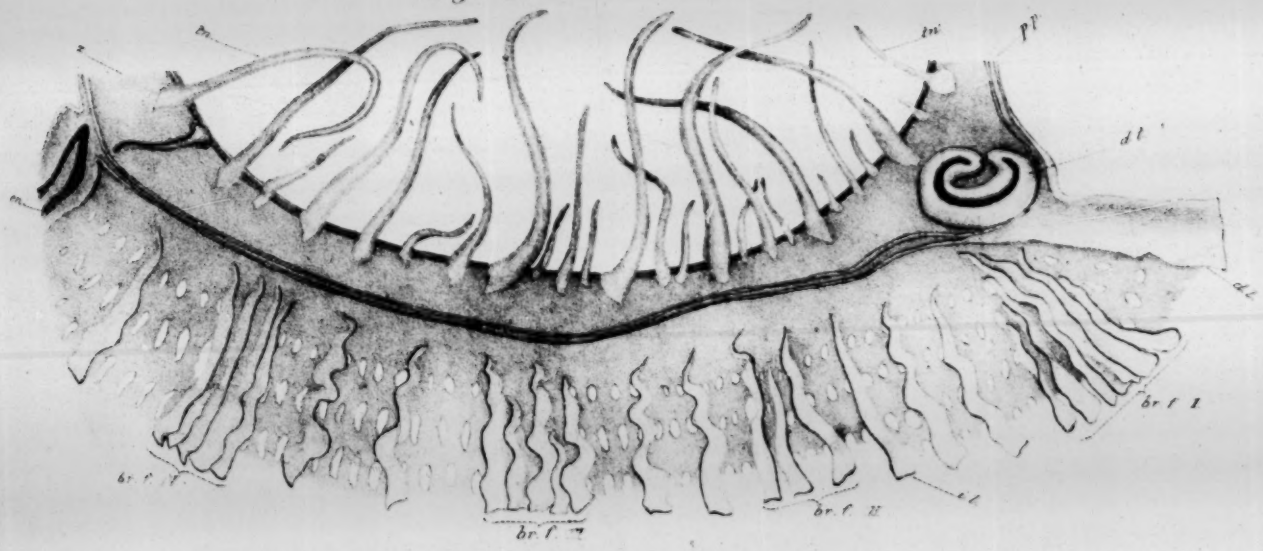


Fig. 5.

Fig. 6.



W.A. Herdman del.

Figs. 1-3. ASCIDIA PLEBEIA. *Alder, var. nov.*

Figs. 4-6. POLYCARPA PUSILLA, *n. sp.*

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Fig. 3



Fig. 4



Fig. 2.



Fig. 1.

Fig. 6



Fig. 12.



Fig. 13.



Fig. 14.



Fig. 5.

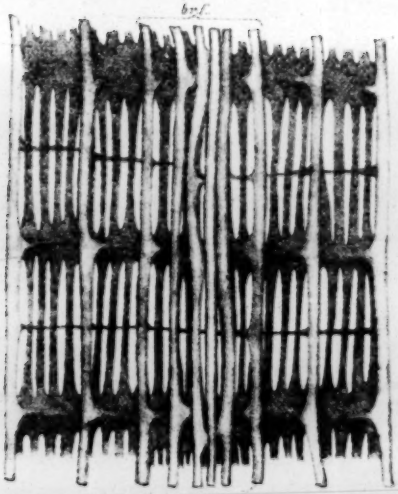


Fig. 8.



Fig. 7.

Fig. 11

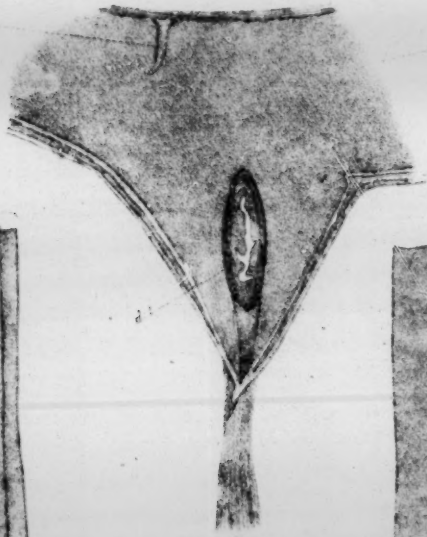


Fig. 9.

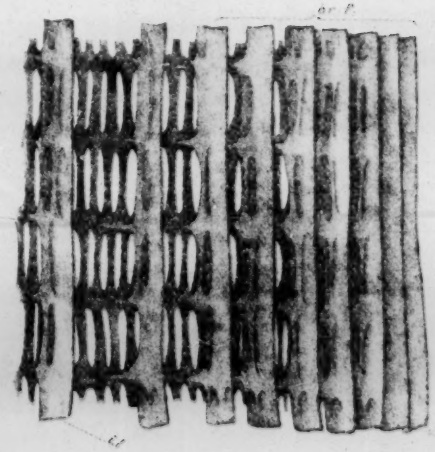
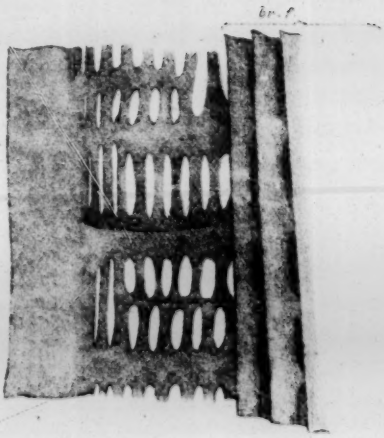


Fig. 10



Figs. 1–6. POLYCARPA FORMOSA *n. sp.*

Figs. 7–11. POLYCARPA CURTA *n. sp.*

Figs. 12–14. EUGYRA GLUTINANS. *Möller.*

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XIV.—*Note on Sir David Brewster's Line Y, in the infra-Red of the Solar Spectrum.* By C. PIAZZI SMYTH, Astronomer Royal for Scotland. (Plate XXXVII).

(Read 17th December 1883.)

Of all known examples in physical science, of simplifying, and at the same time "precisionising" some of its fundamental data, which might otherwise fall to be entangled in high numbers, none has been happier than FRAUNHOFER'S application of the letters of the alphabet to certain chief lines in the solar spectrum. $Ha_{FrF}y$ both in its conception by the inventor, and its universal acceptance since then by the world. Whence it comes to pass now, that in every country, whoever observes the solar spectrum at all, with whatever instrument, large or small, diffracting or refracting, and whether he holds to the undulatory, or any other theory of light, and catalogues spectral lines either in Wave-lengths or Wave-numbers, or merely in terms of the brass scale screwed to his instrument by a maker,—yet whenever he speaks of the line A, or B, or C, or any other so named by FRAUNHOFER, he singles out thereby from among thousands, exactly the same identical line which any and every other spectroscopist alludes to under the same simple letter.

Hardly less happy was the extension of the system made by our great specialist in optical physics, Sir DAVID BREWSTER, when, having discovered several lines in the infra-red of the solar spectrum, beyond or before FRAUNHOFER'S commencing line "great A"—he named them with the later letters of the alphabet, whose stock of symbols had not been more than half used up by FRAUNHOFER in reaching toward the further violet end of the spectrum. Hence, without disturbing any one of FRAUNHOFER'S lettered lines from red through green, to blue and violet, BREWSTER called his new line next beyond, or before great A in the "infra red," by the letter Z; the next before and outside that, Y; and the next before that again, X.

In so far, BREWSTER'S proceeding was quite as happy as FRAUNHOFER'S; and if his assigned letters have been lately misused or omitted in certain high quarters, that is not his fault, and perhaps not intentional on the part of those who have done so, but has arisen *firstly* from the difficulty that many observers have in seeing his lines in the ultra-red, on account of their exceeding faintness; and *secondly*, from some of them being Solar, and others Telluric, to a degree that even he himself had not fully anticipated. It would seem, therefore, to be high time, in BREWSTER'S own Society and Country, to come to a clearer understanding on the facts of his nomenclature, touching at least those three chief

lines X, Y, Z; and the case is all the more claimant just now, seeing that a very grand chemical identification has just been made out in France for one of them; but one, unhappily of late called after one letter by some persons, and another letter by others, a fruitful source of future trouble unless corrected speedily. I propose, therefore, to inquire here, by help of a few recent observations, and reference to many old ones, which is the right letter to employ for each of those three lines.

Sir DAVID BREWSTER'S activities in Solar-spectrum observation were in full force at his favourite Border seat of Allerly, in 1833, as evidenced by three spectroscopic papers in our volume of *Transactions* for that year; but the fullest and most authoritative publication on his new lines in the infra-red is that contained in his joint paper with Dr GLADSTONE in the *Philosophical Transactions of the Royal Society*, London, in 1860.

Of the longest spectrum-view contained in a plate accompanying that paper, I submit a portion copied by myself, as Strip No. 1 of my own plate now presented, with very little alteration, except slightly expanding it to suit my scale; and freely crossing and recrossing the lines representing both shade and the inevitable darkness at and about the very origin of spectrum light, which, beginning on the left-hand side of the picture, rapidly increases in intensity towards the right—FRAUNHOFER lines and bands therein always excepted.

As an observer, I like Sir DAVID'S drawing much, for its truthful representation of the real and necessary degree of darkness, in midst of, or antagonistically to, which the new lines had to be detected; a feature of Nature, this darkness at either end of the spectrum, so rarely introduced in modern spectrum drawings. And though the shade bands are rather too sharply defined on either edge, I recognise, in spite of the depreciatory comments of M. KIRCHOFF, that it is exceedingly like what appears at that end of the spectrum, when a spectroscope is under-prismed and over-telescoped. So too it must most eminently have been in Sir DAVID'S case, when he seems to have employed but one simple prism of not very heavy glass, and no less than a 5-foot achromatic telescope to look into it. But then it was BREWSTER'S eye that looked; so no wonder that he saw with it more than any of his predecessors, and most of his successors as well.

"The light less refrangible than A," say the conjoint authors at their page 150, "is red, but extremely faint, so faint indeed, that few observers of the spectrum have perhaps ever seen it; and the only drawing hitherto published of lines in it appears to be in a map of the solar spectrum by M. MATTHIESEN of Altona. He represents a few lines which, on comparison with fig. 1, may be identified as the band anterior to Y, Y itself, and the band Y^1. In order to map the lines and bands in this portion of the prismatic image, Sir DAVID BREWSTER was obliged to take extraordinary precautions. The telescope was lined with

black velvet, in order to exclude any reflected light; a low power was employed; the slit was made about the eighth, or tenth, of an inch wide,* and the eye of the observer was washed with water to cleanse the fluid that lubricates the cornea. The most prominent line in this space is that marked Y."

That last remark is quite to our purpose, and I trust the drawing-strip, No. 1, of the Plate now given, illustrates it perfectly, remembering that "great A" and "little a" are introduced merely to give milestone references to known parts of the spectrum, and a measuring test universally understood for scale.

Strip No. 2 represents some rude efforts of mine in 1871, with very unequal apparatus, to see something of this rare region of the ultra-red. The drawing is slightly altered from that in Vol. XIII. of the *Edinburgh Astronomical Observations*, inasmuch as the mere general appearances of many close, thin lines unmeasured, and of shading, improperly represented there by vertical lines, are here crossed diagonally and horizontally in such a manner that they cannot be understood to imply true, resolved spectral lines, or anything but shade only, symbolically expressed. And the chief result is thereby plainer than ever, *viz.*, that the Y line was better seen in a high summer, than a low winter, sun; a feature indicating it to be of Solar origin, and not of Earth's atmosphere, or "Telluric" intervention.

Strip No. 3 gives the two views of high and low sun, contained in the Royal Society's Himalaya spectrum, in their *Philosophical Transactions* for 1875. This drawing is on a smaller scale than their's; and their questionable shadings with vertical lines have been changed by me into diagonal lines; but otherwise it represents in exactly the same manner their very surprising negation of the visibility of Y in a high sun, but its abundant visibility, and that of BREWSTER'S Z also, in a low sun.

Strip No. 4 represents on a reduced scale my own observations (from Vol. XIV. of *Ed. Ast. Obs.*) made in Portugal in 1877, with a far more powerful spectroscope than I had ever possessed before, and which I had had constructed specially to look into this particular question of the visibility, or non-visibility, of the Y line in a very high, indeed almost Zenithal, sun. The result, as will be seen in the drawing, was to confirm the previous Edinburgh observation, and to show that Y was, with the sun near the zenith, most notably visible; BREWSTER'S X appearing next in strength; but Z only in the faintest manner possible, if at all.

Strip No. 5 is a very reduced copy of part of a magnificent work derived from photography by Captain ABNEY and Colonel FESTING, forming the Bakerian Lecture at the Royal Society for 1880.

* The distance of this slit is unfortunately not stated. It may have been at the other end of a long room, and was apparently unfurnished with any kind of collimator lens, in the improved manner introduced by Professor SWAN.

By dint of Captain ABNEY's really wonderful processes of changing the colour of silver for transmitted light, he was enabled to photograph not only all that part of the infra-red end of the solar spectrum discovered with so much pain and labour by BREWSTER, but to procure records of other lines, some of them very grand ones too, extending nearly three times as far away, and into what is, to the human eye, absolute, unmitigated darkness. There is, therefore, not the slightest intention here to compete with him in spectral range; and I have purposely left his spectrum strip bright and of full height up to the extreme left hand end of my paper, to indicate that his view extends very much further still in that same direction. The only point of difference in fact which I have with him and his distinguished fellow-labourer, or the Central Metropolitan Society which publishes their work, is,—that the very strong line, which from its place in the spectrum can be no other whatever than Y, he calls Z; and the letter Y he gives no place to.

Apparently Captain ABNEY and Colonel FESTING had not seen the real Z line at all; and with little doubt because they worked in a too high Sun for *it*, though excellent for their other, and chief, objects. For Strip 6 shows the result of three observations which I had the fortune to make during an unusually long, bright sun-shiny afternoon on the 30th of May last at the house No. 15 Royal Terrace, Edinburgh. The apparatus was moderate in power; there was no attempt to resolve bands into their very thin component lines; but only to note the main features of Y and Z, "Great A" being given in as a necessary mile-stone.

At $5^h\ 50^m_1$ P.M. then, of distinct lines, Y alone was visible outside Great A.

At $6^h\ 40^m$ P.M., with a lower Sun, besides Y, there was a suspicion of Z. But

At $8^h\ 0^m$ P.M., with a very much lower Sun, there, besides Y nearly as before, stood out Z as quite a strong line, accompanied too with bands, and proving itself to be Telluric without a doubt.

Finally, Strip 7 represents what the ancient Greeks might have called the apotheosis of line Y, in its glorious identification at last by M. HENRI BECQUEREL, with a bright emission line of the same Solar Sodium (Na), which produces that grand turning-key to all the modern developments of Spectrum analysis, viz., the Solar lines D^1 and D^2.

The fullest account of this final confirmation of the Solar character of Y that I have yet seen is that contained in the *Comptes Rendus* for July 9, 1883, pp. 71-74, by M. HENRI BECQUEREL himself. He had been researching the infra-red spectrum of chemistry by his celebrated Father's method of the phenomena of Phosphorescence, and found two new distinct and widely separated salt lines to exist therein. He next proved the correspondence of both of them with two extra strong and equally widely separated lines at the same points of

the Solar spectrum. One, and the fainter of these two lines, was an immense distance further into visual darkness than any of the lines in my plate. It was even beyond Captain ABNEY's and Colonel FESTING's furthest photographic, being at 23 130 Wave Number. But the other, at 31 010 W.N.—to be freely taken as equivalent to our 30 860—is no less than BREWSTER's Y, and is honourably mentioned by M. BECQUEREL as being such.

It is indeed so instructive, as well as encouraging, to find the line thus alluded to in Paris as "BREWSTER's Y line," three years after that letter was expunged in London from the Solar spectrum, that I beg to conclude with M. HENRI BECQUEREL's own words thus :—

"La vapeur de sodium, qui est principalement caractérisée dans le spectre lumineux par la double raie D, présente dans l'infra-rouge deux très fortes raies caractéristiques dont les longeurs d'onde sont 819 (=W.N.Br. 31 010) et 1098 (=W.N.Br. 23 130). Ces raies sont les mêmes lorsqu'on volatilise dans l'arc, du sodium métallique ou du chlorure de sodium; elles coincide avec deux fortes raies du spectre solaire.

"La raie λ 819 (W.N. 31 010) que l'on peut voir à l'œil nu avec un spectroscope ordinaire, coincide avec une des plus fortes raies du spectre infra-rouge du Soleil que BREWSTER avait vue, et désignée par la lettre Y.

"Dans les conditions ou l'on dédouble les raies D, je n'ai pu dédoubler distinctement la raie Y."

POSTSCRIPT.

The above concluding remark of M. H. BECQUEREL is instructive to those who would desire to see for themselves this salt representative of BREWSTER's Y line; for it shows that even in his "Arc" light, notwithstanding its necessary brilliance, that particular line must have been too faint for neat physical notation; and, indeed, unless an arc light can be prepared as bright as, or possibly still brighter intrinsically than, a high summer sun, such almost must be the result.

With the most powerful Bunsen gas burners, consuming any amount of Chloride of Sodium, the trial is quite hopeless; and even with 1-inch induction sparks, condensed by a half-gallon jar between platinum points, of which one rises through moistened salt, with the effect of making the D lines painfully bright, I have not succeeded in causing the same salt's Y line, or lines, to certainly appear.

I have, however, in the search found three air lines much further towards the infra-red than any of the standard list of air lines entered in Dr WATT's invaluable Index of Spectra, as compiled by him from the observations of the greater spectroscopists.

Though not quite so far to that end of the spectrum as certain two lines of Rubidium, yet being much more constant and more easily procured, these new lines may be useful to other researchers as references for spectrum place in that rather barren region. I give their approximate Wave-number readings therefore here, and have depicted their appearance in the last or "appended" spectrum strip of our table, desiring to remark only, in addition, that the middle line of the three is triple, the distance between its first and second components being rather greater, and between its second and third rather less, than the potassium $\alpha^{1 \text{ and } 2}$ pair, whose Wave-number places are 32 988 and 33 128, respectively; while all the three air lines appear fairly sharp, with a narrow slit, and under a dispersion of 12° A to H, combined with a magnifying power on the inspecting telescope of 15.

Air Line 1, Rel. Intensity = 5, Wave-number place in Brit. Inch = 32 693

Air Line 2,
- Its "a" component, Intens. = 5, W.N.Pl. „ = 33 944
- „ "b" „ „ = 3, „ „ = 34 071
- „ "c" „ „ = 2, „ „ = 34 157

Continuous spectrum begins soon after this, and goes on increasing towards the violet.

Air Line 3, Rel. Intensity = 6, W.N.Pl. in Brit. Inch. = 35 404

First Air Line in Dr WATTS' Index of Spectra, Intens = 6, W.N.Pl. = 38 470

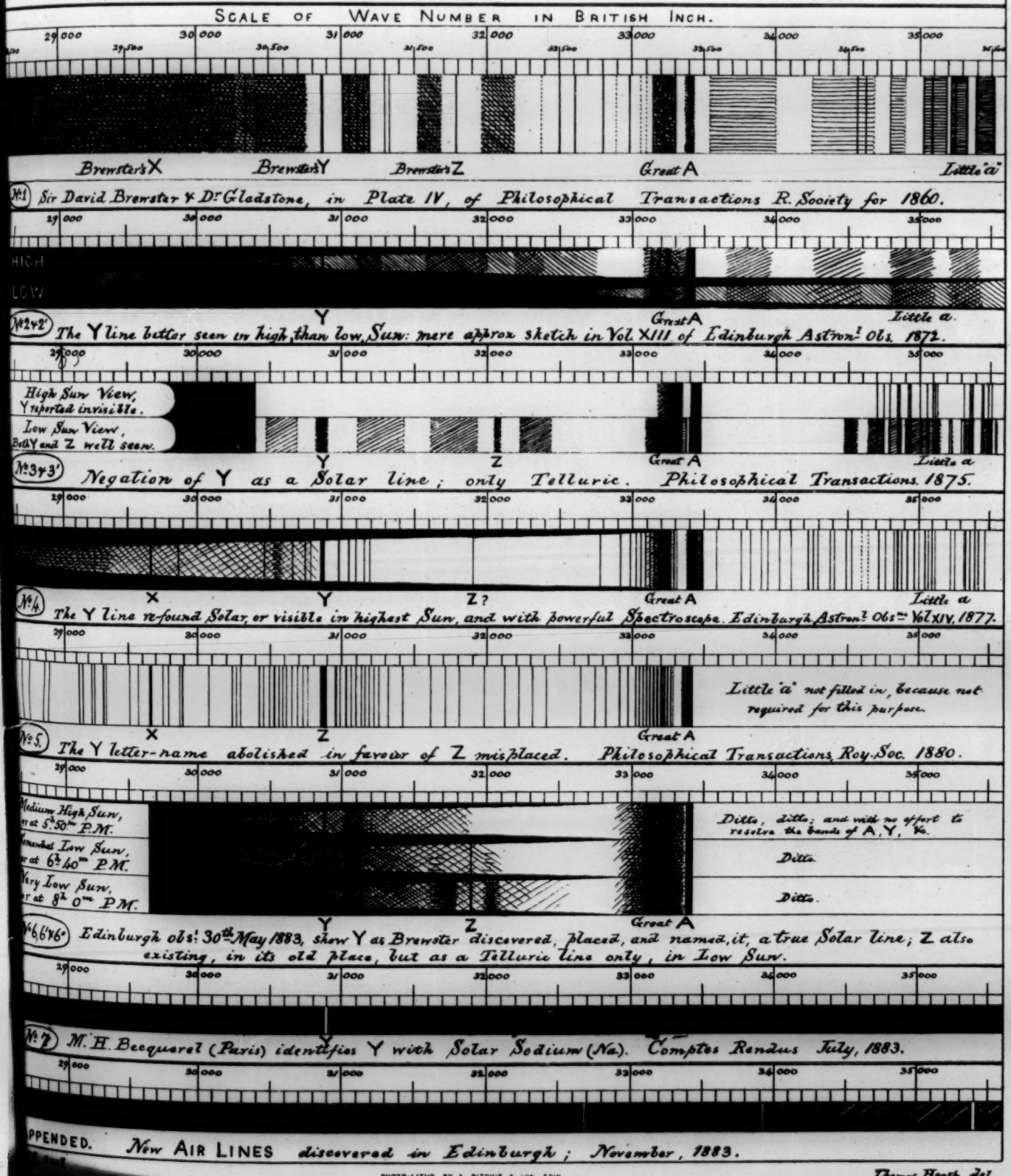
NOTE ADDED ON MAY 30, 1884.

In the course of sundry spectroscopic experiments on vacuum tubes through the winter of 1883–4, and now communicated to Royal Society, Edinburgh, I have had abundant testimony that the first of the lines noted above, viz., at 32 693 Wave-number place, is an oxygen line; a very remarkable one too, for though like all other "tube," or simple-spark, oxygen lines, it is very faint,—yet it is well-defined, and is further towards the ultra red than any line or band I have yet come across in any of the other gases.

The triple line which follows I have equally proved to belong to nitrogen.

But to what gas, air line 3, at 35 404 Wave-number place belongs, I have obtained no indication as yet from vacuum tubes. C. P. S.

Approximate Spectrum Drawings for the History of Sir David Brewster's Line Y in the Infra-Red of the Solar Spectrum.



APPENDED. New Air Lines discovered in Edinburgh; November, 1883.

PHOTO-LITHO. BY A. RITCHIE & SON, EDIN.

Thomas Heath del.

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XV.—*On the Formation of Small Clear Spaces in Dusty Air.* By Mr John Aitken. (Plate XXXVIII.)

(Received December 27, 1883; read January 21, 1884.)

The dust particles floating in our atmosphere are every day demanding more and more attention. As our knowledge of these unseen particles increases, our interest deepens, and I might almost say gives place to anxiety, when we realise the vast importance these dust particles have on life, whether it be those inorganic ones so small as to be beyond the powers of the microscope, or those larger organic ones which float unseen through our atmosphere, and which, though invisible, are yet the messengers of sickness and of death to many—messengers far more real and certain than poet or painter has ever conceived.

As the great importance of these dust particles is gradually being realised, we are from time to time increasing our efforts to protect ourselves from these invisible enemies. Professor, now Sir Joseph, Lister has shown us how to contend successfully with those organic germs, which, falling on our wounds, there find a suitable resting-place, and, if not killed, germinate and grow to our destruction. Sanitary societies are every day being formed, one of whose objects is to combat these floating particles by better appliances directed towards the prevention of the conditions suitable for the germination, growth, and increase of these germs, and against their spread from infected centres, while other societies are directing their energies against the artificial production of those inorganic forms of dust which pollute our atmosphere.

The immense importance of everything connected with dust must be my excuse for bringing before this Society observations on phenomena which I fear must appear to many as trivial and uninteresting; as the clear spaces to which I shall direct attention are on almost a microscopic scale, and require to be magnified to enable us to see them clearly.

Professor Tyndall has made many experiments on the light-reflecting particles floating in our atmosphere. He found these particles were destroyed by heat, and that by placing a flame under a brilliant beam of light, which revealed by illuminating the dust in the air, there was seen rising from the flame wreaths of darkness resembling intensely black smoke. He then found it was not necessary to burn the particles to produce this stream of darkness. This was observed when a hot metal ball was placed under the beam of light, and permitted to remain till its temperature had fallen below that of boiling water. It

was then found that, though the dark current was much enfeebled, it was still produced. To study this effect, Professor TYNDALL stretched a platinum wire transversely under the beam, the two ends of the wire being connected with the poles of a voltaic battery, and the necessary appliances for regulating the strength of the current. "Beginning with a feeble current, the temperature of the wire was gradually augmented; but long before it reached the heat of ignition a flat stream of air rose from it, which, when looked at edgeways, appeared darker and sharper than one of the blackest lines of FRAUNHOFER in a purified spectrum" (see fig. 5). He goes on to say—"Right and left of this dark vertical band the floating matter rose upwards, bounding definitely the non-luminous stream of air. What is the explanation? Simply this: The hot wire rarefied the air in contact with it, but it did not equally lighten the floating matter. The convection current of pure air therefore passed upwards among the inert particles, dragging them after it right and left, but forming between them an impassable black partition." *

This explanation of Professor TYNDALL's has been received by most of us without question; yet I think that if we try to form a mental picture of the process which is here supposed to go on, we shall have some difficulty in doing so. Professor TYNDALL supposes the distribution of the floating matter is due to the heat, which lightens the air, but does not in the same degree lighten the floating dust; the tendency, therefore, he says, is to start a current of clear air through the mote-filled air. No doubt the lightening of the air will slightly increase the tendency of the motes to fall, but the increased freedom to fall from this cause will be extremely slight and inappreciable, and will be entirely negatived and overruled by the upward movement of the hotter air, and the result will be simply to cause the particles to lag a little behind the air in their movements.

Our confidence in Professor TYNDALL's explanation was not, however, shaken till Lord RAYLEIGH, in going over Professor TYNDALL's experiments and extending them, discovered that the explanation given of the formation of the dark plane was not correct, and showed that it could not be due to heat lightening the air, and so enabling it to shake itself free from the dust motes, because he discovered that cooling the air produced a precisely similar result (see fig. 2). Lord RAYLEIGH introduced a cold glass rod into smoky air, and then found that "a dark plane extending *downwards* from the rod, clearly developed itself, and persisted for a long while." † He says—"This result not merely shows that the dark plane is not due to evaporation, but also excludes any explanation depending upon an augmentation in the difference of densities of fluid and

* *Proc. Roy. Inst.*, vol. vi. p. 3, 1870; also *Essays on the Floating Matter in the Air*, p. 5. Longmans, Green, & Co., 1881.

† Paper read before Royal Society, December 21, 1882; also *Nature*, vol. xxviii. p. 139.

foreign matter." Lord RAYLEIGH also offers as a suggestion that the particles may be thrown out by the centrifugal force, as the mixture flows in curved lines round the obstacle.

In a letter to *Nature* of July 26, 1883, Dr LODGE gives an account of some experiments he made on the dark plane and on dusty air. Dr LODGE says—"We are now pretty well convinced that differences of temperature have nothing to do with the real nature of the phenomenon; *we find that solid bodies have sharply defined dust-free coats or films of uniform thickness always surrounding them*, and that these coats can be continually taken off them, and as continually renewed, by any current of air." Dr LODGE also describes a number of interesting electrical experiments on the dust, and makes many very valuable suggestions, but comes to no definite conclusion. He says—"*Why* the air near a solid is free from dust we are not prepared to say."

From these quotations it will be seen that the whole matter is involved in considerable obscurity; and as the subject already had considerable attractions for me, I determined to undertake an investigation in this particular direction. My experiments were begun in summer, but it was not till November that the greater part of the work was done.

I have considerable difficulty in determining how it will be best for me to place the result of this investigation on record. As a rule, it is best to take the reader over the road traversed by the investigator, as the probability is the difficulties of the one will be the same as those of the other, and the results generally unfold themselves best when treated in this way. In the present occasion this method is not suitable. The subject, though apparently simple enough, was found to be much more intricate and complicated than was expected. The result was, many a false scent was followed only to be given up, so that I would be taking the reader to my conclusions by a long, winding, and uninteresting path. It will therefore be better for me simply to describe the result of the investigation from my present point of view.

Apparatus used.

The apparatus used was all of the simplest and least expensive kind. The dust-box in which the experiments were made was a cigar-box, the lid of which was removed and a piece of glass put in its place. When in use the box was placed on its end, with the glass to the front. A window was cut out of the left side of the box, extending from close to the bottom to near the top, and coming close to the front of the box. The box was then painted black inside. Holes were cut in the back of the box, or wherever required for the introduction of the different pieces of apparatus, which shall be afterwards described. As a source of illumination, two gas jets, placed close to each

other, were used; these jets were enclosed in a dark lantern, having an opening towards the dust-box. To concentrate the light, two double convex lenses were fitted into a short tube. This tube was loosely attached to the front of the dark lantern, and could be directed to, and focused on, any part in the interior of the dust-box. For observing the phenomena two magnifying glasses were employed —one a simple double convex lens, which was used for getting a general view of the phenomena; the other a more powerful compound glass, strong enough to enable me to see and follow the movements of the individual dust particles.

For observations on the effects of slight differences of temperature, metal or glass tubes in some form or other were generally used. Straight tubes closed at one end were found most convenient; these tubes were introduced through the back of the box, and the closed end projected inwards to within a short distance of the glass front, so as to admit of observation under the strong magnifying glass. The tubes were heated or cooled by means of water or steam introduced into them through a small tube which passed down their interior. This small tube was connected by an india-rubber tube to a glass filler, into which the water was poured, and from which it flowed down the small tube to the front end of the experimental one, and returned to the outside of the box by the space between the tubes. In this way the experimental tube could be easily heated or cooled, and the space all round it left free for observation. For higher temperatures, a fine platinum wire, heated by means of a small bichromate of potash battery, was employed.

Different kinds of dust were used in the experiments, such as dust made in the usual manner with hydrochloric acid and ammonia, and by burning sulphur in the presence of ammonia; this last was used when very dense fogging was required; smoke of paper and other substances were experimented with; also dusts made by burning sodium or magnesium; and for experiments with dust which would not change with heat, calcined magnesia and lime were employed. Charcoal powder was also used in some experiments. The powders of these last three substances were stirred up by means of a jet of air. These dusts were also varied by the addition of water vapour.

Suppose now that the gas is lit in the lantern, and the dust-box in its place Let us introduce into the box through the opening in the back one of the glass or metal tubes, closed at the front end, and introduce into this tube from the back the smaller one, and connect this latter with the filler, so as to enable us to pour hot or cold water through the tube, to heat or cool it. If we are going to use smoke, a piece of smouldering brown paper is introduced into the box, by removing the glass front, which is kept easily removable for this and other purposes; or, if we are going to use sal-ammoniac dust, the ammonia and hydrochloric acid can be introduced on glass or wooden rods through small openings in the box, or the acid and ammonia may be placed in small open vessels inside the box. If the dense sulphate dust is required, the sulphur

may be placed on a match and introduced into the box after being lighted. When the dust is thick enough, and uniformly distributed through the box, bring the light to a focus on the tube. For the present the tube must be neither heated nor cooled. Using the magnifying glass; it will in all probability be found that there is a clear space all round the tube or on some part of it, and that the air currents are carrying off the clear space in an irregular manner, or there may be seen rising over the tube a regular dark plane, depending on the relative temperatures of the air and the tube.

Now remove the beam of light from the dust-box and leave it for some time. If left long enough, and the box kept free from changes of temperature, it will be found that all air currents have ceased, and a close examination of the experimental tube will show that the dust is now in contact with it at the sides and on the top. But if we look on the under side of the tube we shall there see a clear space, like that shown in fig. 1, which represents the tube seen endways.* It will be observed that this does not agree with Dr LODGE's observations; but I think I have taken every precaution, and the conclusion which I have come to is, that bodies have not sharply defined dust-free coats, and that when the bodies and the air have the same temperature, the dust comes into contact with the sides and top of the bodies.† Now what is the cause of this clear space under the tube? Clearly

Gravitation,

which brings me to the first of the causes of the dark plane. When the air comes to rest, the temperature of the air and the tube being the same, there is nothing to keep the dust from coming into contact with the tube. But gravitation is at work on the particles, and while the air is still the particles are all falling, and as the upper surface of the tube stops those falling on it, there are no particles to supply the place of those falling from the space under the tube, and the result is that a dustless space is here formed. If now we pour into the tube some cold water we can study the

Effects of Cold.

At once a downward current is started, and this downward current carries with it the clear air under the tube; the two currents of dustless air from the sides

* In the figs. the white surface represents the light-reflecting dusty air, while the black represents the transparent air, free from reflecting particles.

† The only reason I can imagine for this difference between Dr LODGE's results and mine is that he worked with more powerful sources of illumination than I did. He used either the sun's light, an oxyhydrogen lamp, or a SERRIN arc-lamp, while I only used gas. Now one result of this difference would evidently be that the illuminating beam used by him would have a much greater heating effect than the one used in my experiments, and would therefore heat the surfaces under examination. I found this effect even with gas. If the body had a small capacity for heat, it was only necessary to keep the light focused on it for a short time to heat it sufficiently to cause a clear space to form over the part where the light acted.

of the tube meet underneath it, and form a dark plane in the centre of the descending current, as represented in fig. 2.

It might be thought that gravitation would not act quickly enough to keep up a supply of dustless air sufficient for this purpose. This however does not seem to be the case, and gravitation appears to be the only cause of the distribution of the dust, causing this dark plane in the descending current. One reason for supposing this is, that if we only cool the tube very slightly, the dark plane is very thick and well marked; but the more we cool the tube the thinner does the dark plane become, intead of thicker, which would be the result if it was due to difference of temperature. The effect of the increased cold is to increase the velocity of the descending current, and draw out and thin down the dark plane. Further, if we closely examine the air round the tube with the strong magnifying glass, we shall see the particles of dust descending and settling on the horizontal part on the top of the tube, while the particles which fall a little to each side of the centre line are carried on by the current, and continue to clasp the tube closely till the current begins to turn under the tube, where the particles being free to fall, drop away from the tube, and leave a clear space (see fig. 2). This clear space only begins to be perceptible when the current begins to turn underneath the tube, and gradually becomes thicker as it travels underneath towards the centre where the two currents join, and form the descending dark plane.

The rate at which dust settles out of air by gravitation is much quicker than we might imagine. Dust is kept in suspension by ascending currents, and when these are removed it settles remarkably quickly. There was an opportunity for seeing this in these experiments. If the experimental tube was cooled, then the cold gave rise to currents descending on the side of the box where the tube was, and rising on the other side; but the rising current only came up to the height of the tube, and all the air above the tube was still and currentless, because its temperature increased towards the top of the box, and then was produced a condition of stable equilibrium. Under these circumstances, I have frequently seen the whole of the upper part of the box above the cold tube become quite clear, and with a sharp line of demarcation between the clear still air above, and the dusty currents underneath. It is, of course, the vertical component of the currents that keeps the dust in suspension, the horizontal component having no such action. This may be seen when we cause a current of dusty air to flow along the under side of a horizontal flat surface. At the point where the current starts, the dust is in contact with the under surface of the body, but falls further and further from it as it flows along.

In order to study the effect of temperature alone, it was necessary to arrange the experiment so as to get rid of this gravitation effect. For this purpose I prepared another piece of apparatus. The ideal shape of body for

this purpose would be one having some length and breadth, but infinitely thin and flat, so that when placed vertically, the air in passing over it would never have to move in a horizontal direction. The nearest approach I could make to this was made with a piece of copper foil folded on itself, soldered all round its edges, and fixed to the end of a brass tube. It was heated and cooled by passing into it hot or cold water. This instrument presented at the front edge extremely little thickness, and was found to answer well, but was rather delicate and easily put out of shape. As it is only necessary to examine one side of the test plane or surface, a different form of apparatus was afterwards adopted. It was made of a piece of brass tube the same as used in the previous experiments, and a flat plate of copper was soldered to one side of it at the front end. This plate was filed perfectly flat and smooth, and sharpened at the top and bottom edges, all the bevel being on the tube side of the plate. The side of the plate presented towards the source of illumination was thus a perfectly flat surface, and when placed vertically, the air passing over the front surface could not have its dust separated from it by gravitation, as *all* the horizontal movement went to the back of the plate.

Placing either of these test surfaces in the dust-box with the plate vertical, cold was applied. At once a downward current was produced, but no dark space was formed on the vertical test surface; and if the copper foil apparatus, which is flat on both sides, is used, no dark plane whatever is formed, as shown in fig. 3. More intense cold was tried, and a temperature of -10° C. in air of a temperature of 15° C. was found to produce no effect save an increased rate of current, and an increased brightness in the particles near the plate, due to water vapour being deposited on them by the lowering of the temperature, an effect observed by Lord RAYLEIGH on the dust bounding his cold dark plane. Different dusts were tried, and the experiment varied in many ways, but when the gravitation effect was removed, not the slightest tendency to the formation of a dark plane by cold could be detected. The tendency seemed to be the other way. The dust particles in all cases tended to keep close to the cold body. This indicates that Lord RAYLEIGH's dark plane formed in the descending current from a cold body is not an effect of the cold, but is due to the separating action of gravitation.

What I am about to state may at first seem a contradiction of this conclusion. When varying the conditions of the experiment, and altering the amount of water vapour present, I was much surprised to find that under certain conditions the dark plane had a decided tendency to make its appearance in the descending current even from a thin vertical surface. On repeating the experiment and varying it, it was found that the conditions best suited for getting this dark plane were when there was nothing but ordinary atmospheric dust in the box, and the air was saturated with water vapour. Under these conditions, there was generally all through the box a haziness, but in the space in front of the cold test

surface the cold thickened this haziness into a dense cloudiness, which extended for some distance from the plate and showered down from it. But between the fog and the test surface there was a well-marked dark space. To what was this due? I had already satisfied myself that cold did not tend to drive away the particles. Then why did these particles conduct themselves differently from the others? While the test surface was vertical, the motion of the particles was too quick to be followed with the magnifying glass. The surface was, therefore, placed nearly horizontal, with a slight slope towards the light (see fig. 4). Still the dark space remained, and the current flowed on, but the particles did not come close up to the plate, though gravitation was acting on them. The cold could surely not be repelling the particles and keeping them off the plate. A short examination with the strong magnifying glass, which it was now possible to use as the particles were moving slowly enough, showed that this was not the case. The particles were seen flowing along in the current, but at the same time they were seen falling into the dark space and disappearing when they came within a certain distance of the surface. The explanation was evident. The surface, by its very low temperature, had robbed the air close to it of its moisture, which it deposited on itself in ice crystals. Into this cold but drier air the particles evaporated as they fell, and in this case the dark plane would contain the dust of the atmosphere, which, however, is black, compared with the brilliancy of the surrounding fog. In this case the dark plane was produced by

Evaporation,

and this explains why it is not visible when artificial dusts are present, the larger particles of the artificial dusts not being sufficiently reduced by evaporation to make them comparatively invisible. We shall now pass on to consider the

Effects of Heat.

For this purpose let us remove the flat test surface from the smoke-box, and put in its place a round tube of metal or glass. A glass one is preferable, as it permits the illuminating beam to pass through it, and we are thus enabled to see what is taking place all round. After the box is filled with dust, leave it for some time, till the tube has acquired the same temperature as the air. On examination we shall find, as before, the particles evenly distributed, and coming close up to the surface of the tube on the top and at the sides, while underneath we shall see the clear space produced by gravitation. We shall first examine what the effect is of a slight difference of temperature. For this purpose we shall pour some slightly heated water through the tube, so as to raise its temperature a very little—a degree or two. When this is done the equilibrium is destroyed, and currents begin to form. The clear space formed by gravitation under the tube rises up, closely clasping and encircling the tube in

a dustless envelope. The two currents of clear air which started from the under side of the tube, reunite at the top after passing round the sides, and ascending in the centre of the upward current, form a well-marked dark plane (see fig. 5). Here again gravitation seems to be the principal cause of the distribution of the particles. This certainly is the case when the difference or temperature is very slight, but we shall see that, as the temperature rises, the gravitation effect bears a less and less proportion to the heat effects, which we shall presently consider. It will be as well to note here the difference in the clear space surrounding the tube in this case and when cold was applied, as shown in figs. 2 and 5. When cold was applied (fig. 2), the dark space was only on the under side of the tube ; but with heat it is all round the tube, because it has its origin in the air under the tube.

When making these experiments a somewhat peculiar effect was often noticed, which seems worth recording, as it forms a good illustration of the influences at work here. If, after the tube had been warmed and a well-marked dark plane formed over it, no more hot water was added, and the tube allowed to cool, the upward current became sluggish after a time, and the dark space presented the appearance shown in fig. 6. The two sides of the tube now differed. The left side was bounded by a clear space, which ascended as before, but on the other side, the dark space did not continue to the top of the tube. As shown, the particles here came into the dark space and obliterated it. The explanation of this peculiar effect, which so often repeated itself, is this. The falling temperature had allowed the current on the right side to become so slow that gravitation had time to act on the particles after the current turned to the upper side of the tube, and the particles had time to fall through the clear space before they were carried into the ascending current over the tube. In other words, gravitation undid on the upper part over the tube what it did at the under. The left side of the tube continued to keep its clear space, because the light used for illuminating it was focused on this side; it, therefore, was slightly warmer than the other.

Gravitation, while it explains the formation of the dark plane in such cases as above described, where the difference of temperature is slight, is evidently not the whole explanation. Gravitation can obviously have little to do with the formation of the dark plane formed over a thin wire, as the time occupied in horizontal movement when going round so small a body is not enough for it to have any appreciable effect. In order to study the effects of heat apart from those of gravitation, the tube with the flat surface fixed on it, employed in the experiment with cold, was used, as it eliminates the gravitation effect and shows the heat effect alone. Fixing this piece of apparatus in the smoke-box with the test surface carefully adjusted in a vertical plane, heat was slowly applied to it. An upward current at once started, and it was noticed that at

the same time a clear space was formed on the hot surface, and rose up from it, producing a dark plane in the ascending current (fig. 7). This clear space was evidently entirely due to the heat in some way driving the particles away from the hot surface.

When working with this flat test surface it is necessary to be careful about the adjustment of it in a vertical plane. If the surface leans either to the one side or to the other, a clear space is, of course, formed on the side to which it inclines by the separating action of gravitation, and gravitation also acts on the particles on the other side, and tends to counteract the effect of the heat. Further, if the surface is inclined enough, the gravitation effect overcomes the heat effect, and destroys the dark space by causing the particles to fall towards the hot surface. At the same time, the gravitation dark space on the under side becomes thicker and thicker the more the plane of the test surface approaches the horizontal. This instrument may be made capable of measuring the relative effects of different temperatures, &c., by providing it with a scale to indicate its angle with the vertical. The greater the angle at which the dark space is visible the greater will be the repelling force.

By the construction of the instrument, when placed vertically, the gravitation effect is entirely removed. The dust particles can be seen coming straight up, and no purified current coming from the under side (compare figs. 5 and 7). The clear space begins to show itself with a very slight rise of temperature. Indeed, it would appear that it is formed by the slightest rise of temperature, as it always begins to be visible just when the temperature is high enough to cause an ascending current. With a slight difference of temperature it is extremely thin, and requires careful observation to detect it, but as the temperature rises it becomes thicker and thicker. For the present I shall not enter into the question as to why the dust particles move away from a hot body, but shall leave the consideration of this subject till after describing some experiments which seem to throw some light on the mechanism of these movements. For the present I shall simply speak of it as repulsion due to heat.

The following experiments will help us to understand the action of this repulsion. Fix a piece of glass in front of, and parallel to, our flat test surface, and at a distance from it of two or three millimetres. Glass is used because it is transparent, and allows the illuminating beam to penetrate and show us what is taking place at the different surfaces. If we now warm the test surface, the dust particles all move away from it towards the glass plate, and many of them attach themselves to the glass. After a short time the glass gets warmed by radiation, &c., from the hot test surface. If we now cool the test surface a change takes place, the dust particles move away from the glass, and crowd up towards the colder test surface.

A better form of the experiment is shown at figs. 8 and 9. A glass plate

A, 12 cm. long and about 4 cm. broad is attached by means of cement, near its upper end, to a metal tube, to enable us to heat it while in the dust-box. Another plate of glass B, of the same size as A, is placed opposite and parallel to it, at a distance of about 5 mm. The plate attached to the tube is first put in its place in the box, and after it has acquired the temperature of the air, the other plate B is warmed and put in its place, opposite to A, as shown in sketch. The box is now filled with dust. If we now carefully examine the air between the two glass plates, we shall find that the warm plate B (fig. 8) is bounded on each side by a clear space, its high temperature having driven all the dust particles to a distance, while the other plate has no clear space round it. Now let us put a little warm water into the tube to heat the upper part of the cold glass plate A, and note the change in the distribution of the dust. As before, the lower part of B is bounded by a clear space (see fig. 9), but the upper part of A being now warmer than B, the dust is driven from A towards B, and a clear space opened in front of the hot part of A, while the clear space formerly in front of the upper part of B is closed. The heat has thus caused the dust particles to move across the direction of motion of the air. These experiments have been made with different dusts, and always with the same result.

For the purpose of studying the effects of higher temperatures than that of boiling water, a fine platinum wire was fitted up inside the dust-box and heated by means of a small bichromate battery. The arrangement of wire which I prefer for this purpose is made by bending it into a U-shape and bringing the two legs close together, say one or two millimetres apart. The wire is placed horizontally in the dust-box, with the bend to the front, and the legs at the same level, the two copper wires to which it is attached being carried backward and out of the box. By this arrangement a clear end-view is obtained all round the wire, and the effect of the heat conveniently observed, and further, the wire doubled in this manner, tells us more than a single wire can.

In experimenting with this arrangement of apparatus, the results are as varied as the dusts employed. Each dust gives a different size of dark plane for the same temperature. The previous experiments with less intense heat seemed to point to repulsion as the cause of the clearing away of the particles. If this were the case, it seemed very unlikely that some dusts would be repelled further away than others, at least to the extent that actually took place. To see if repulsion was the explanation in this case also, instead of a single wire, which I used in my first experiments, I doubled the wire into a U-shape, as already explained, and placed the length horizontally, with the legs at the same level. When this wire was heated in the sal-ammoniac or in sulphate dust, it was at once evident that repulsion was not the cause of the dark plane in these dusts. With either of them, when the temperature of the wire was not

very high, the dark plane rising over each leg was very thin (see fig. 10), but as the temperature rose, the planes extended on each side till the two planes met and formed one large one (see fig. 11). An examination by means of a magnifying glass showed that this broad dark plane was due to the evaporation, or to the disintegration of the particles, as they could be seen streaming upwards and disappearing into the dark space under the wires. They there arrived at a space the temperature of which was sufficient to convert them into gases or vapours. The dark plane in this case was thus due to a change of the particles from the solid to the gaseous state. Hence the great differences in the size of the dark planes of different dusts, each kind of dust having a different temperature at which it evaporates or becomes disintegrated. The sulphate dust, for instance, gives a smaller dark plane than the chloride, because the sulphate requires a higher temperature to drive it into the gaseous state than the chloride.

This result is quite different from that got with temperatures which were not sufficient to vaporise the particles and make them invisible. It was therefore now desirable to make experiments with some substance which a high temperature could not destroy. For this purpose I selected calcined magnesia and calcined lime, also soda and magnesia dusts, produced by burning the metals. With these dusts a different result was obtained. A high temperature had no other effect than forming a thin dark plane over each wire (see fig. 10). But even these stable forms of dust were subjected to a repulsion, the particles passing near the wire being driven to a small distance from it on each side. It may be possible that some of the particles of these dusts are vaporised, but if so, the amount must be very small, and can have but little influence on the formation of the dark plane.

Another effect noticed in these, and in the experiments at lower temperatures, was that whenever there was much water vapour present, there was a faintly indicated dark plane formed by the evaporation of the water from the particles. If nothing but the dust of the air was present in a fog formed with steam, then the wires were surrounded by a very thick dark plane, due to the evaporation of the fog particles; and if any artificial dust was present, then the thick dark plane was still visible, but not black, as the particles were only reduced in size by the evaporation of the water from them. All these different effects of the hot wire can be illustrated at one time, if we put into the dust-box some indestructible dust, also some sal-ammoniac and sulphate dusts, in proper proportion, and then add some water vapour. When the wire is heated in such a mixture, we get a result like that shown in fig. 12. In the centre we have the true dark plane, in the wider space there is only the indestructible powder present. The next boundary shows the vaporising zone of the sulphate, the next the vaporising zone of the sal-ammoniac dust, and the last that of water. In fig. 12, *a* is the true dark plane, in which there is nothing but gases and

vapours; in the wider space *b*, both the chloride and sulphate dusts are vaporised, and we have nothing visible save the indestructible dust; in the next space *c* the chloride is vaporised, and there are present the sulphate and indestructible dusts; while in the space *d* all the dusts are present, but dry, the condensed water being evaporated.

Conclusion.

The conclusion we have arrived at from these experiments is, that for the formation of the dark plane in dusty air, there are various causes which may be classed under the following heads:—With cold, producing the downward dark plane, we have—1st, the distributing effect of gravitation; and 2nd, the disappearance of the particles by evaporation, when falling into a space rendered dry by condensation produced by cold. With heat, producing the upward dark plane, we have—1st, the distributing action of gravitation; 2nd, the distributing action of repulsion due to heat; 3rd, evaporation of the particles; and 4th, disintegration of the dust. In the last two cases the dust is rendered invisible by the heat changing it from the solid light-reflecting condition to the transparent gaseous state.

Effect of Centrifugal Force.

We may here ask ourselves, Are these the only ways in which the dark plane may be produced? It is, of course, impossible to give a definite answer to such a question. There are, no doubt, other ways in which it seems possible that this phenomenon might be produced, and it seemed worth while to consider Lord RAYLEIGH's suggestion as to the effect of centrifugal force. On considering the action of this force in the experiments described, it is evident that it can have but little to do with the distribution of the particles, because the air, in rising and passing round the wires and tubes, is curved first in one direction, and before it again takes up its original direction of motion, it is curved to an equal amount in the opposite way. So that whatever sifting action the centrifugal force may have at the one part of its course, will be undone at the other. I, however, thought it worth while to arrange an experiment, to see if the particles really were thrown out by centrifugal force at any part of their passage. With this object, I fixed inside the dust-box a piece of thin sheet metal, with its plane vertical. Arrangements were made so that a current of dusty air was caused to flow down the one side of the plate, round the lower edge, and up the other side. In this way the air was caused to curve through an angle of 180°, and no curving in the opposite direction took place. When this was done, it was seen to be possible to give an appearance very like as if the centrifugal force did throw the particles away from the centre of motion. In front, and just above the lower edge of the plate, there was formed a clear space,

very near the centre of rotation of the air. On examination, however, it was seen that this was caused by an eddy, due to the upward channel in which the air was confined being wider than the space under the plate. In the eddy so formed the particles were soon sifted out by gravitation, and a clear space formed. On contracting the breadth of the upward channel, and making it equal to the passage under the plate, this eddy disappeared, and the clear space was no longer formed. In this experiment, though the air was caused to curve through a considerable angle, yet there was no satisfactory evidence of any distributing action due to centrifugal force. It seems probable that, even under these conditions, a certain amount of sifting action does take place, though not enough to make it observable; and though there are reasons for supposing that if the particles were heavy enough, and the velocity of the current great enough, there would be a visible effect, yet it is evident that centrifugal force plays no part in the formation of the dark plane, in the experiments with heat and cold. The fact that the dark plane has a sharply defined boundary is proof that centrifugal force is not the cause of the distribution, as this force would not give such a result. Its tendency would be to throw the heaviest particles furthest out, and thus give rise to a shaded outline.

Effect of Electricity.

Electricity is another force which might be supposed to play some part in the formation of the dark plane. It was difficult to believe that the attraction of the particles was a thermal effect when making the experiments with the hot and cold surfaces placed opposite each other, and observing the way in which the particles were repelled by the one plate and attracted to the other; and on making other experiments, which will be presently described, in which the dust rising in the current from the heated platinum wires was attracted to, and deposited itself on, the surfaces of bodies placed in its path. The dust particles conducted themselves in a way strongly suggestive of electrical disturbance. They seemed to be attracted by the cold surfaces in exactly the same way as if they had become electrified at the hot surface. It was, therefore, thought advisable to make experiments to ascertain whether electricity had anything to do with the formation of the dark plane. Experiments were first made to see if the hot surface became electrified in the dust-box by the passage of the air over it, or from other causes. For this purpose I used a small cylindrical conductor of solid metal, about 1 cm. in diameter, and with rounded ends. This conductor was fixed to the end of a glass tube, and a conducting wire connected to it and carried through the tube. The conductor was then introduced into the dust-box through an opening in the back, after which its connecting wire was joined to a gold-leaf electroscope. Before the conductor was put in its place it was

heated, and the box was filled with dust. Examined with the magnifying glass in the usual way, the dark plane was found to be well marked and the repulsion going on as usual, but not the slightest sign of electrification showed itself at the electroscope. No signs of electricity having shown themselves at the hot surface, it was sought for in the ascending current. This was done by first removing the insulated heater and putting in its place the platinum wire, to get a more intense effect from the high temperature. Over the wire was placed a large insulated flat-shaped conductor for the dust to deposit itself upon. The conductor was then connected to the electroscope, the box filled with dust, and the electric current turned on to heat the wire. The leaves of the electroscope, however, remained close together, so that the dust deposited on the conductor could not have been charged with electricity.

It may be objected to these experiments that the electroscope used was not sensitive enough for the purpose, and that if a more sensitive instrument had been employed, signs of electricity might have been obtained. It is quite possible that another instrument might have shown signs of electrical disturbance, but I think that if electricity was the cause of these phenomena, and was sufficiently strong to repel the particles and to cause them to adhere to bodies, it would be quite powerful enough to separate the leaves of the electroscope. Any electrification less than would affect the leaves would only be a secondary matter, and could not be the cause of the phenomena. Another reason for supposing that electricity has little to do with these effects is that the dust tends to settle only on cold surfaces.

Experiments were now made to see what the effect is of electrifying the hot surface. The small cylindrical conductor was heated, placed in the box, and connected with the electroscope. A Leyden jar charged very slightly, but enough to cause the full divergence of the leaves of the electroscope, was then connected with the apparatus, and the effect on the dust surrounding the electrified conductor noted. While the body was hot enough to cause a well-marked dark plane, there was not the slightest effect produced by the electricity, though the leaves of the electroscope were wide apart, and showed that the hot surface had a decided charge. The electroscope was then removed, and a much higher charge given to the conductor. This time an effect was evident, but it was difficult to say what was taking place. The general appearance of the air round the hot conductor had quite changed. The sharp outline of the clear space round it was destroyed, and the dark plane over it had lost its clear and sharp outline, and had become much thicker, though not so dark, as before. All round the conductor there seemed to rage miniature storms, and the particles had much the appearance as if they were seen all out of focus. This effect was produced by either positive or negative charge.

To find out what was taking place in the air round the electrified body, I

had recourse to large-sized particles of dust to enable me to follow the movement of each particle. Calcined magnesia was selected for this purpose. When the air in the dust-box was filled with this powder, the reason of the change in the dark space at once became evident. The particles in the ascending current could be seen rushing towards the electrified surface and adhering to it. The dark space was thus broken in upon, and its outline destroyed by the attracted particles; the air round the body was at the same time deprived of a great quantity of its dust; and over the conductor there rose a thick and ill-defined band of clearer air, the particles which formerly were in it having attached themselves to the electrified body. All the particles did not seem to be equally attracted, but some much more than others. This gave rise to the irregular movements seen all round the body. The dust particles frequently deposited themselves on the conductor in small needle-like radial columns, which grew by the addition of the particles till they got to a certain size, when they were shot off and flew through the air with surprising velocity. If, after the conductor had been electrified a short time, the supply of electricity was cut off and the conductor connected with the electroscope, the charge given to the air and the dust in the box was given back. The leaves of the electroscope expanded quickly, and if discharged, rapidly became charged again, the dust at the same time being attracted to and deposited on the conductor in needle-like columns.

After looking at this last experiment, and seeing the tendency which particles in electrified air have to deposit themselves on bodies, we cannot help asking the question, Does this experiment throw any light on the well-known tendency to the development of certain forms of bacteria resulting in the putrefaction of our foods, and in the appearance of increased quantities of certain ferments during thundery weather? Can it be that the germs of these forms of life floating in our atmosphere have a far greater tendency to settle upon the surface of bodies from electrified air than when there is no electrical disturbance? No doubt this electrical attraction must have some effect in this direction, but whether it is the principal cause or not I shall not venture to say.

If we use still higher degrees of electrification than those used in the above experiments, other effects are produced, but they have no relation whatever to the formation of the dark plane. From the experiments described it will be seen that the effects of electricity are of quite a different kind from those of heat. The electrified body, instead of repelling the particles like a hot one, attracts them, and clears the air in a partial way by attracting some of the particles to itself, while heat acts by repelling all of them to a distance. This antagonism between the two forces may be illustrated by heating the conductor and electrifying it slightly. At first no effect is produced by the electricity; the

dark plane remains quite clear, but as the temperature falls, a stage is arrived at when the electrical effect overcomes the heat effect, and the particles break in on the dark space and destroy it.

In making electrical experiments, most of us have noticed the tendency which dust in the room has to settle on the different parts of the electrical apparatus, and to destroy the insulation, and many have noticed the excited and rapid movements of electrified dust. Dr LODGE, in the letter already referred to, remarks on the rapidity with which the dust-box, in his experiments, was cleared of its dust by means of electrified bodies placed inside it. I have made some experiments on this subject, to determine the conditions most favourable for the clearing of air by means of electricity. For these experiments I preferred to use a large glass flask about 30 cm. in diameter. Placing this flask with its mouth downwards, I introduced into it an insulated metal rod, fixed vertically, and passing through the open neck of the flask. If a dense cloudiness was made in the flask with any dust, by preference it was generally made by burning sulphur and adding a little ammonia. After a dense whiteness had been produced, the conductor was electrified. Seen from a distance, no change seemed to have taken place, but on examination it was found that all the dust was deposited on the inside of the flask in a nearly uniform white coating. To enable me to see what was taking place, the inside of the flask was wetted. When the electrification began, the dust could now be seen driven about as by a violent wind, and, after a few turns of the machine, it had disappeared from the flask. The conditions found most suitable for producing this result quickly were a rapid discharge of the electricity into the dusty air by means of a point or points. If the conductor terminates in a ball inside the flask, the electrification has but little effect. In addition to the conductor terminating in a point, it is also necessary to have near the electrified point surfaces to aid in the rapid electrification of the dust. When the point is surrounded by surfaces the air currents are violent, but if we remove the surfaces the currents are not nearly so strong. This may be seen by allowing a cloud of dust to rise round a conductor placed in an open space, when but little effect will be observed on electrification. After the dust has been electrified, it ought to be brought near some surface, towards which it may be attracted, otherwise it may lose its charge before meeting a place to deposit itself.

Experiments have also been made to determine whether the very fine and invisible dust of the atmosphere is also caused to deposit itself when electrified. With this object the large glass flask had an india-rubber stopper fitted to it, through which passed a tube to connect the interior of the flask with an air-pump, to test the condition of the air in the flask by reducing its pressure, while it was kept moist by the presence of water, and to observe whether any cloudy condensation took place after electrification. A conductor insulated in

a glass tube passed through the stopper, and terminated in a point inside the flask. Means were taken to insure the insulation of this conductor inside the flask. This was done by surrounding the insulating tube with another tube, and causing the entering dry air to pass into the flask through the space between the tubes. The insulation was thereby kept good, and the glow of the discharge at the point was quite visible in the midst of the moist air.

On experimenting with this apparatus, it was found that electrification for a short time by means of an ordinary cylindrical electrical machine was sufficient to deposit almost all the dust, only the very slightest signs of condensation being visible after electrification. What formed the nuclei of the very few cloud particles which appeared it is difficult to say. Whether they were undeposited dust particles, or particles thrown off the conductor, or some product of the electric discharge, this experiment does not determine. That they may be some product formed from the air by the electric discharge is suggested by the following experiment. First purify the air in the flask, either by passing it through a cotton-wool filter, or by electrification, then reduce the pressure to supersaturate it, and now electrify. At once a cloud forms all round the conductor, and extends to near the sides of the vessel. This cloud is evidently not formed by anything thrown off the conductor, forming nuclei, as it appears at the same moment all round the point. It is more probable that the nuclei of these cloud particles are formed by the discharge of the electricity producing in the air nitric acid, or ozone, on which the supersaturated vapour condenses. That the nuclei so formed are not solid particles there seems to be but little doubt, because if we allow filtered air to enter so as to increase the pressure and evaporate the particles, cloudiness does not reappear on again reducing the pressure, which it certainly would do if the nuclei had been solid particles. The number of nuclei that remain after electrification is very small, if the air is not supersaturated with vapour; and practically we may say that electrification deposits all the very fine dust, and I may remark here that it does it in a very rapid manner. The air in the flask can be purified much quicker by means of electricity than by the air-pump and cotton-wool filter. It may be noted here that the dust of the atmosphere has but little effect on the brilliancy of the glow of the point discharge. With a large amount of dust, with the ordinary dust, with no dust, and with the electrification used, no difference of importance in the brightness of the glow was detected.

The Lungs and Dust.

When we see a beam of sunlight shining into a darkened room through a small opening, and revealing, by illuminating, the suspended dust, making the beam look like a solid body, we have great difficulty in realising that our atmo-

sphere can be so full of dust, as this experiment shows it to be, as it escapes our observation under ordinary conditions of lighting, and it gives us a feeling of discomfort to realise that we are breathing that dust-laden air. This uneasiness was by no means decreased when my experiments on cloudy condensation revealed the fact that, in addition to that mass of visible dust, there are enormous multitudes of particles so small that even the concentrated light of the sun does not reveal them. These minute particles are so numerous that hundreds of them are crowded into every cubic centimetre of air. On realising these facts our feelings are those of wonder that our lungs can keep so clean as they do, while such vast quantities of impurities are constantly ebbing and flowing through them. At that time I was not aware that there is an influence ever at work tending to protect the lungs by preventing, to a certain extent, the particles of dust coming into contact with their surfaces,—that nature had provided a subtle form of mechanism possessing some of the advantages of a filter without any of its disadvantages. The experiments here described show that a hot surface repels the dust particles in the air. The heat of our bodies will, therefore, exert a protective influence on the lungs, and tend to keep them free from dust.

Our lungs, however, are not only hot, they are also wet. What influence will the constant evaporation which takes place at the surface of the tubes and passages have on the dust? To answer this question, I fitted the flat test surface in the dust-box, and through an opening in the top introduced a brush dipped in water, with which one-half of the surface was kept wet, the other half being dry, to compare the effects under the two conditions. When the surface was heated a few degrees, to even less than the temperature of our bodies, the result was most decided, the dust being driven more than twice as far from the plate in front of the wet part as it was from the dry. The evaporation, therefore, of the water from the surface of the bronchial tubes tends strongly to ward off the dust, and keep it from coming into contact with their surfaces. We must not, however, imagine that the heat, or the heat and the evaporation, are sufficient entirely to prevent the dust coming into contact with the surfaces of our bronchial tubes and passages, because dust really does come into contact with them, but it does not do so nearly to the extent to which we have been in the habit of supposing.

The necessary conditions for this repulsive effect to be active are, that the air is acquiring heat and moisture. If the air has the same temperature as our bodies, and is saturated with vapour, this force no longer exists, and gravitation and other forces are free to act.

Although the repulsion due to heat and evaporation are not powerful enough to form a perfect protection to the lung surfaces against the contamination of dust, yet it is very evident that their protective influence will have a

most important effect on the condition of our lungs, and one towards which I wish to direct the attention of those who make this organ a special study. There seems to be but little doubt that we have here an explanation of some of the effects of different climates. For instance, what a difference there must be in the amount of dust deposited on the lungs from air breathed at, say, St Moritz or Davos Platz, and at such places as Madeira or other similar health resorts! These remarks are altogether apart from the question of the amount of dust in the air at the different places, and refer only to the action of the lungs on the dust which may be present.* In the Alpine resorts the air is cold and dry, and the tidal air, which flows backwards and forwards through the bronchial tubes, is in the very best condition for preventing the dust coming into contact with their surfaces, as the difference in temperature between the air and the body is great, and the air is also capable of causing a rapid evaporation. Whereas, at such places as Madeira, where the air is hot and moist, the repelling forces are both at a minimum. The effects of these different conditions on the lungs seems well worth study.

In illustration of the protective influence of heat and moisture many experiments may be made, but the following is perhaps the easiest. Take an ordinary paraffin lamp, raise the flame till a very dense cloud of smoke rises from it. Over the lamp place a very tall metal chimney, to produce a quick current of air and also to cool it. Have ready two porous cylindrical jars (porous jars are used because they keep up a supply of water for evaporation), one jar filled with water slightly heated, and the other with cold water. Cover both jars with wet white paper. Now introduce the hot one into the top of the chimney, and leave the black wreaths of smoke to stream over it for say half a minute, then take it out and put in its place the cold one, and leave it for the same length of time. The result will be, the hot one will be quite clean, not a speck of soot on it, while the cold one is covered with soot. It is not, however, so black as a cold dry surface would be, as the slight evaporation from its surface tends to protect it.

We must not, however, suppose that the lung surfaces are so well protected as the paper in this experiment. In the lungs the currents are quicker, they do not flow over such uniform surfaces, and further, they pass round curves, so that in the lungs dust tends to deposit where the currents flow quickly where they strike on the concave side of curved passages and on projecting edges. Further, all dust which penetrates beyond the tidal air and gets into the residual air will ultimately fall on the surfaces of the tubes and air-

* The amount of dust breathed by invalids at the two places will not be greatly different, as most of their time is spent in the house, and the air in the rooms at the two places will be nearly equally dusty. The higher temperature inside will slightly reduce the thermal effect, but will not diminish the rate of evaporation.

cells. This tendency of the dust in the residual air to settle is increased by the load of water deposited on it by the moist air.

The amount to which our lungs are protected by heat and evaporation can scarcely be solved in a physical laboratory, and will be best determined by anatomical examinations of lungs which have lived under different conditions of temperature and moisture.

A Thermic Filter.

Having observed that the dust particles tended to move away from hot bodies and to attach themselves to cold ones, I made some experiments on the subject to study the movements of dust particles when placed between hot and cold surfaces. Most interesting results were obtained by placing near the hot platinum wires, already referred to, a piece of glass or a plate of metal, and getting the dust deposited upon it. One arrangement of the experiment is to place the glass with its plane vertical and transversely over the wires, at such a height that its lower edge almost touches the wires, and fill the box with dust by blowing up some calcined magnesia or other fine powder. After all the currents have settled, and while the air is still full of dust, the electric current is turned on and the wire heated. A well-marked dark plane at once rises over the wire, and in its upward passage it is cut transversely by the glass plate. After the plate has been left for some time with the air current streaming over its surface, it is found to have a very beautiful impression of the dark plane imprinted on it. The warm air, in streaming upwards over the surface of the glass, deposited its dust on it, and the fact of there being no dust in the dark plane is recorded by a well-defined line of clear glass, the deposit of dust on each side of the clean line being thickest just along the edge, and thinning away on each side. These impressions of the dark plane may be made permanent by causing the dust to be deposited on a plate newly coated with black varnish, and used while the varnish is still soft.

It is not necessary to put anything on the surface of the glass to cause the dust to adhere, as it attaches itself to a clean surface of glass with considerable firmness, but some adhesive substance on the plate enables the impression to stand rougher treatment. Impressions of the dark plane have also been made with charcoal dust deposited on opal glass. These black impressions are, of course, "negatives" of the magnesia ones, the plane in the former case being white, surrounded by black dust. The charcoal dust was securely fixed by first coating the glass with a thin solution of gum, which was dried before the dust was deposited on it, and the dust fixed by breathing on the surface.

If in place of putting a plate vertically over the wires, we place two plates vertically—one at each side of the wire—we then get the dust deposited on the plates, thickest opposite to the wires and thinner higher up. Arrangements

were made for studying the action of surfaces placed on both sides of the wires. Fixing the plates parallel to each other, and at a distance of 2 or 3 mm. apart, with the platinum wire between them, I carefully watched the motions of the particles carried up in the air current. As the particles approached the wires they gradually changed the direction of their motion, and instead of coming straight up they curved towards the sides, some of the particles striking and adhering to the side plates at a point below the wire. Some rose higher and stuck opposite to it, others went higher still, while others passed on to the top and escaped.

I had for some time been trying to arrange an experiment in which I should be able to watch the movements of the individual particles of dust, so as to see them moving away from the hot surface. My intention was to examine the movements of the particles with a microscope of low power, or with a powerful magnifying glass. My great difficulty, however, was to get the movements due to the convection currents sufficiently slow to enable me to follow the moving particles when much magnified. After making the experiment last described, I saw it was possible to arrange for this much-desired observation. The use of the large particles of magnesia enabled me to dispense with the microscope, and use only a magnifying glass of moderate power; and by bringing the plates on each side of the wire close together, the velocity of the upward convection current could be greatly reduced by the friction of these surfaces, and by their cooling effect on the gases. The two side plates of glass were accordingly brought closer together, to a distance of about 1 millimetre. Fig. 13 represents the arrangement magnified five times, the U-shaped wire being shown in section between the plates. The ascending current was now very slow, and no difficulty was experienced in following the movements of the individual particles, so I had at last the satisfaction of seeing the particles being repelled by the hot wire.

When the wire, heated to a red heat in air filled with magnesia dust, was examined by means of a magnifying glass, the spectacle which presented itself was most curious and interesting. At a distance below the wires, the particles could be seen coming straight up between the glass plates, but as they approached the wires they seemed to get uneasy, and as if wishing to avoid the heat, some of them attached themselves quickly to the glass, others went further up, but soon curved towards the sides and adhered to them; while others boldly advanced straight up, almost to the wires, when their motion was suddenly arrested and they were driven downwards and sideways, and attached themselves to the glass. If the wires were hot enough, not a single particle got past them, and the glass plates had each a patch of magnesian powder adhering to its surface *below* the level of the wires. The direction of movement of the particles is roughly indicated by the lines in fig. 13.

These experiments naturally suggested the possibility of constructing an air filter on thermic principles. They showed that the visible particles of dust could be thrown out of the air, as the particles tended to move from the hot parts, and to attach themselves to cold surfaces. But the question which naturally suggested itself was, Are the very small invisible particles also arrested? If the thermic filter turned out to be a success, it appeared to me it would also be the best way to get an answer to this question. In order to filter air on thermic principles, all that appeared necessary was to pass the air through a space or channel, the two sides of which were kept at different temperatures. In this way I hoped the dust would be driven from the hot side and attach itself to the cold one. Practically to carry out this idea, the simplest method that suggested itself was to pass the air through the space between two concentric tubes, the one tube being kept hot, and the other cold. In the preliminary instruments which have been made, the distance between the tubes forming the space through which the air passes, is in one instrument less than 1 mm., but in other instruments this space is nearly as much as 3 mm. The length of the passage in the different instruments is about 35 cm. One of these instruments has the outer tube jacketed by means of a larger pipe for the purpose of heating it with steam. The other instruments were heated simply by means of a gas flame. The filter is shown in section, fig. 14. A is a tube about 13 mm. diameter. B is another tube slightly larger, and allowing a space C, between the two for the passage of the air to be filtered, which enters and leaves by the tubes D, D. The outer tube E forms a steam jacket round B. F, F are pipes for steam entering, and for condensed water leaving the jacket. The pipe A is kept cold by means of a stream of water. In working the instrument it is not, however, necessary to keep to this arrangement; steam may be admitted to the centre tube A, and cold water to the outside jacket; both arrangements do equally well. For the purpose of cleaning and examining the surfaces of the air channel, the centre tube was not permanently fixed in its place, but was so arranged that it could be easily taken out, and the joints were made tight by means of the short pieces of india-rubber tube H, H. The air, after passing through the space C, was conveyed by means of a tube to a glass flask, in which there was a little water. The flask in turn was connected by means of another tube to an air-pump, in order to test the condition of the air after passing through the instrument. If cloudy condensation is produced when the pressure is reduced in the flask, we know that the air is not filtered; and, on the other hand, if the air remains perfectly clear on exhausting, we know that no dust, not even the invisible particles, have passed into it.

The apparatus was fitted up for trial, all the connections being made and tested. Using the instrument heated with flame, the first effect of the heat, as expected, was a great increase in the fogging. The temperature was raised

as high as it safely could be, to cleanse the instrument thoroughly; after which, as we know, it will cease to give off nuclei at a lower temperature. When the tube was thoroughly cleansed by means of heat, and all the impurities swept out of it by a current of air, the temperature was lowered slightly, and the air allowed to pass slowly through the tube on its way to the test-flask. After this, the fogging in the flask gradually diminished, and after passing through the rainy stage, it ceased entirely, proving that the filter was doing its work thoroughly, not a single particle—not even one of the very minute and invisible ones—escaping it. On equalising the temperature, either making both tubes hot or both cold, the filtering action of course ceased.

It does seem somewhat strange that air should be freed from all its dust in passing through a channel large enough for a fly to pass, if it has sufficient intelligence to keep always on the cold side. All who have experimented on this subject know that dust can get through any opening, however small. On testing this filter for the first time, I failed to get a satisfactory result. I however felt convinced that it ought to work, and the failure was attributed to some imperfection in the tubing or joints. Arrangements were therefore made for testing the tightness of the whole apparatus. The one end of the filter being connected, as described, to the glass flask in which the air was tested, I now connected a cotton-wool filter to the other end of the thermic filter, and proceeded to test if all was tight, by drawing in air from the cotton-wool filter through the apparatus, while it was cold. At first, I could not succeed in getting air free from dust; fogging always took place on reducing the pressure in the flask, showing that dusty air was leaking in somewhere, and mixing with the filtered air. After much time spent in remaking all the joints, it was discovered that the air-pump valve was not quite tight; by allowing the leakage to bubble through the water in the flask, it was found to be very slight, only about 2 or 3 c.cm. per minute. After this was put right, fogging still appeared, showing that there was still leakage. This time it was traced to the stop-cock between the filter and the test-flask. This leakage was smaller than the other, yet it let in dust. After all leakages had been stopped, the cotton-wool filter was removed, and the thermic filter being heated, was now found to do its work satisfactorily, though more slowly than a cotton-wool filter. The ease with which dust passes through small openings is surprising; indeed, I have found that any opening which admits air, also allows these less than microscopic particles to pass, and yet the air in its passage through the wide channel of this filter had every particle of dust taken out of it by the thermal conditions to which it was subjected.

If we cause the filter to purify air into which we have intentionally put a good deal of dust, such as dust of calcined magnesia, we find all the dust collected on the surface of the cold tube, near the end where the air entered,

while the hot tube is quite clean. If we send the smoke of a cigar through the filter, nothing but perfectly transparent gases come out at the other end. The effect of coating the cold surface with glycerine has been tried, as it seemed possible that the dust deposited on the clean surface might be carried on by the air current. The dust, however, seems to be firmly held on a cold clean surface, and no decided improvement was got by the addition of the glycerine. No accurate experiments have been made to determine the best size of the filtering channel. The filters with very narrow passages and those with much wider ones all work well, but no quantitative experiments have been made as to their relative values.

It is not easy to determine what influence difference of temperature has on the action of a cotton-wool filter. Heating the cotton-wool has little effect in reducing its filtering powers. We might expect this, as the cotton and the air passing through it rapidly acquire the same temperature; and it is extremely difficult to say how much of the action of this filter depends on the slight differences of temperature produced by the air in passing through the cotton.

Diffusion Effects.

I shall now describe two experiments on diffusion, which were made in the hope they would throw some light on this repelling action of hot bodies. For this purpose a tube similar to those used in the previous experiments was taken, and an opening made in the side of it, at the front end. Into this opening was fitted a thin plug of plaster of paris. The surface of the plug was made flat, and when put in the dust-box was placed vertically, as in the experiments on the heat effect, to get rid of the distribution due to gravitation. This diffusion diaphragm was blackened, to enable the effect to be better observed, as a white surface reflects so much light, it makes it difficult to see what is taking place.

After the diffusion apparatus was fitted in its place, the dust-box was filled with sulphate dust, and left till everything had acquired the same temperature. Carbonic acid gas was then introduced into the tube. At once a downward current was produced in front of the diaphragm, the dust particles kept close up to its surface, and if there was any tendency to the formation of a clear space the carbonic acid at once closed it. The apparatus for supplying the carbonic acid gas was then removed, and a small pipe connected with the gas pipes was then led into the diffusion tube, so as to get the effect due to the diffusion of gases lighter than air. The effect in this case was the opposite of that given by the carbonic acid. An upward current at once started, and a thin clear space formed in front of the diffusion diaphragm. These experiments prove *that the dust particles move in the direction in which the greatest rate of diffusion takes place.* This at first sight looks very self-evident; but we must remember that in front of the diffusion diaphragm, when hydrogen is coming

through it, that the ascending clear space is not composed entirely of the lighter gas which has come through the diaphragm. In that clear space the larger proportion of the molecules are air molecules; and while the air molecules advance up to and pass through the diaphragm, the dust particles are driven away from it. I shall presently have to refer to this.

When speaking of the action of heat and moisture in protecting the lung surfaces from contact with the suspended dust in our atmosphere, no mention was made of this diffusion effect, as it can be better considered here. In our lungs the small quantity of tidal air, which flows backwards and forwards, carrying in the oxygen, and out the carbonic acid, never gets further than the main bronchial tubes, and does not penetrate to the air-cells; the carbonic acid, set free into the residual air in these cells, is carried outwards to the tidal air by diffusion, and at the same time oxygen is diffused from the tidal air towards the residual air. Now, what is the effect of this diffusion on the distribution of the dust? We have seen that in diffusion through a porous diaphragm the dust moved towards the carbonic acid. If this was the case in our lungs, then the dust would tend to penetrate towards the air-cells and come into contact with their surfaces. In our lungs the exchange between the carbonic acid and the oxygen does not, however, follow the law of diffusion through a porous diaphragm, but those of osmose; and the rate of passage of these gases through the lung surfaces does not depend upon their relative densities, but on much more complicated conditions, of which solubility is in this case one of the principal. The result is, that in our lungs for every volume of oxygen that passes inwards, exactly or almost exactly one volume of carbonic acid passes outwards. These diffusion effects balance each other, and the result is that diffusion has no tendency to cause dust to penetrate towards the air-cells, or to adhere to the surfaces of our lungs.

Repulsion due to Heat.

We shall now consider the cause of the repulsion of the dust particles by hot bodies, and see if we can make out the mechanism by which the particles are driven away. This is a subject of considerable difficulty, and one on which I fear there will be much difference of opinion, and I shall simply state here what appears to me at present to be the cause of the particles moving away from a hot and towards a cold surface. The simplest explanation, and the one which offered itself first, was that possibly it might be a radiation effect, and that the particles are repelled in the same way as the vanes of a Crookes' radiometer by the reaction of the heated gas molecules in the way explained by Professors TAIT and DEWAR. We might suppose the side of the particles next the hot surface to be warmed by radiation, and the gaseous molecules on that

side getting heated by contact, would rebound from it with greater velocity than those on the other side, the dust particles being thus driven away in a sort of rocket fashion. On examination, however, this explanation does not appear satisfactory; because the particles are so very near the hot surface that they will not be heated principally by radiation, but by contact with the hot gases near the heating surface, radiation having but a slight effect.

So far as I have been able to form a mental picture of the mechanism of this repulsion, it seems to be produced in the following way:—First, let us go back to the diffusion experiments. We saw that when hydrogen was diffused into air, a clear space was formed over the diffusing surface. Now why was this? The air molecules were moving towards the diaphragm and passing through it, yet they did not carry any dust particles with them. The reason seems to be this. In the air in front of the diaphragm there are two currents of molecules—one of hydrogen, moving outwards from the diaphragm, and one of air, moving inwards; but as the hydrogen current is the stronger, it carries the dust particles along with it, and the difference in the strength of these two currents in this case gives rise to a thin clear space over the diffusing surface.

Let us now apply the same reasoning to the heat effect. When we remember that hot and cold gases tend to diffuse into each other, the explanation given does not require to be greatly altered. The molecules of air on the surface of the hot body get heated by contact, and these molecules tend to diffuse themselves outwards into the colder molecules. In imagination, let us look at a section of the air close to the hot body. The air there is no longer homogeneous. Some of the particles have more kinetic energy than others. Those molecules with the greatest kinetic energy have the greatest amount of their motion in a direction away from the hot surface, while the cold ones have the greater amount of their motion in a direction towards the hot surface. Now what will happen to any particle of matter hung among these heterogeneous molecules? The side of the particle next the hot body will be bombarded by a larger proportion of hot molecules than the other side, and the result will be to drive the particle away from the hot body. It may be objected that, as the air pressure is the same on the front and back of the particles, therefore the total energy of the molecules on the front and on the back must be the same, and therefore there will be no tendency to cause the particles to move. I think, however, this does not correctly represent the case. Near the heating surface the hot molecules are moving outwards and the cold ones inwards. If there were more cold ones moving inwards than hot ones outwards, so that the total energy of the inward moving ones was equal to the total energy of the outward moving ones, which would be necessary in order that the pressures might be equal, then no motion would be produced in the dust particles. We must, however, remember that there are exactly the same number of molecules moving each way. One effect

of the hot surface seems to be to differentiate the movements of the molecules, causing the greater amount of the movement of the hot ones to be outward and of the cold ones inward, and the outward moving molecules, having the greater kinetic energy, exert a greater pressure on the dust particles and drive them outwards. In the hydrogen diffusion effect the particles of dust were driven away, because a greater number of hydrogen molecules were moving one way than air ones the other. In the heat effect they are driven away, because the molecules moving *from* the hot surface have a greater kinetic energy than those moving towards it, and the particles are bombarded on the one side by a greater number of hot molecules than on the other.

We have the same effect intensified when the hot surface is wet. When this is the case, the vapour molecules diffusing outwards carry with them the dust particles to a much greater distance than the heat alone, as there is no inward current of vapour molecules to contend with the outward one, and tending to drive the dust particles inward; the result is, we get a dark plane at least twice as thick with heat and vapour as with heat alone. Of the two, the vapour seems to be the more powerful, as very little heat with moisture gives a thicker dark plane than double the heat would do. If we carefully fix the experimental test surface in a vertical position and simply wet it, the effect is to cool it by evaporation, and a downward current is produced; but, at the same time, a clear space is formed, showing that in this case the outward effect of the vapour is greater than the inward effect of the cold.

There seemed to be a possibility of getting an answer by experiment as to whether the radiation or the diffusion theory is the correct one. If radiation is the cause of the repulsion, then we should expect that a good radiator would cause the particles to be driven further away, and thus cause a thicker dark plane than a bad radiator. For the purpose of testing this, another experimental flat test-surface was prepared. This test-surface was made of silver and highly polished. One-half of it was then covered with lamp-black. After the test-surface was fixed in the dust-box heat was applied to it, and the thickness of the clear space over the two halves of the test-surface carefully noted. To do this, the dust-box was so arranged that I could look down the test-surface—not across it as usual—and could thus see down the boundary line between the dark plane over the polished surface and over the lamp-black. The result was, not the slightest difference could be detected between the two. The boundary line of the dark space in front of the plate was a straight line parallel to the surface of the plate. This experiment, while it gives no support to the diffusion theory, shows us that radiation is not the principal cause of the dark plane.

If the explanation here given of the repulsion of the dust by a hot surface is correct, then this effect is not produced in the same way as the repulsion of the discs of a Crookes' radiometer when heat is falling on them, but is similar to

the repulsion of the discs by a hot surface placed *inside* the radiometer bulb, as in the apparatus described by Mr CROOKES in *Nature*, vol. xv. p. 301. In this radiometer the vanes were made of very clear mica, and they did not rotate when light fell on them. Inside the bulb, and just clear of the discs, was fixed in a vertical plane a blackened plate of mica. When the light was allowed to fall on this fixed and black plate, the vanes instantly rotated as if a wind were issuing from this surface. The energy which causes the repulsion of the dust and of the discs of this radiometer is transferred in both cases from the hot surface to the repelled surface by the kinetic energy of the gas molecules, and not by radiation.

Another consideration which indicates that the force causing the movement of the dust is not transferred by radiation is the well-known fact that radiant heat is not much intercepted by dust. When we concentrate a strong beam of light and heat in dusty air by means of a lens, perhaps one of the things which strikes us most is the very slight heating effect which is developed at the focus. The dust is not destroyed, and no rapid upward current is formed. But if we place a piece of paper at the same focus it is at once charred, and a rapid current of air rises from its heated surface.

The rate at which vapour molecules diffuse under the conditions existing in the experiments is very great, and seems to be quite sufficient to account for the results. Take, for instance, the water molecules when they pass into vapour. Vapour molecules are selected because we can follow their movements. In a small fraction of a second they diffuse to a distance of nearly 1 cm. This can be seen in the experiment described with the flat test-surface when moistened. With a slight rise of temperature, fog particles are seen forming in the current, rising in front of the wet surface. Even at the lower edge of the plate these particles are seen at some distance from the plate, and separated from it by a dark space, showing that even at that point the vapour molecules have already diffused outwards to a distance and far beyond the dark space, while probably other molecules have gone further than the fog boundary, but are under conditions which keep them in the state of vapour.

Or take the reverse of this diffusion process, seen in the evaporation of fog particles. Let us blow some steam into the dust-box, so as to form a regular fog, but without adding any dust. Into this fog introduce a piece of very dry wood; if it is charred so much the better, as its blackness enables us to see more easily what is taking place. It will be observed that there is formed all round the wood a clear space, in which not a particle of fog can be seen. If we watch the air currents we shall see the particles approaching, but vanishing at some distance from the wood, and over the wood the particles will be seen falling into the clear space and disappearing. This clear space is caused by the wood absorbing the vapour in the air near it, thus surrounding itself with

a space of dry air, into which the fog particles evaporate as they approach, and so rapid is the diffusion towards the wood that the air is kept dry enough to evaporate the particles as quickly as they approach.

Attraction Due to Cold.

To explain the attraction of the dust particles by cold surfaces, we have only to reverse the explanation given of the repulsion due to heat. At the cold surface the outward moving molecules of air have less kinetic energy than the warmer inward moving ones, and the dust is thus driven towards the cold surface by the greater energy of the hot molecules.

This explanation of the action of hot and cold surfaces may not at first sight seem satisfactorily to account for the peculiar movements of the dust particles as they approached the hot wire, in the experiment shown in fig. 13. We might here ask ourselves, for instance, Why were some of the particles carried close to the wire, and then driven away from it? The inertia of the particles is clearly not sufficient to cause them to advance against the force which produced their rapid repulsion. Then why did they approach so close to the wire, and then appear driven away with such violence? It looks as if the particles had become heated to a temperature sufficient to drive off their occluded gases and condensed vapours, and that the repulsion in this case was due to the rapid escape of these gases and vapours. No doubt, something will be due to their escape, but I do not think it is the principal cause of the repulsion, because the particles are so small, the gases and vapours will escape from their surfaces all round them, and their effects will therefore nearly balance. Further, the escape of these gases will not explain why the particles were always driven towards cold surfaces. The following seems to be the principal reason why the particles are always driven sideways and not downwards. The rate at which a particle of dust will be repelled from the surface of a body is not necessarily the same in all directions round the body, but will depend on the closeness of the isothermal lines at the different places; and as in the experiment the temperature varies very much more rapidly towards the cold glass at the sides than it does downwards, the result is, a more powerful impulse is given sideways than downwards; and further, the cold glass surfaces differentiate the molecular movements near them, and cause an attraction.

Let me illustrate this point further, and show by a parallel case in the action of gravitation, why it is that the particles of dust when repelled move towards the side, and not downwards. Suppose there is a very long, but narrow and regularly shaped mountain, with its highest point near the middle, and the sides sloping regularly and quickly to the summit, while the ridge descends slowly. In ascending such a mountain, we can either go up the long easy slope of the

ridge, or up the steep sides. Now, suppose a stone to be rolled up the ridge of this mountain, by a force acting in a direction along the ridge, it is evident that if the stone gets off the ridge, that it will fall down the quicker slope towards the side; and if the stone keeps the ridge, and we succeed in rolling it nearly to the summit, but there meet a slope too steep for us to push the stone up, then the stone will obviously be in a position of unstable equilibrium, and the slightest fall will cause it to leave the easy slope of the ridge, and, once started on the quick descent of the sides, its motion will be rapidly accelerated in a direction at right angles to that in which we are pushing; thus the stone will descend the quick slope of the side with great velocity, even while the force which pushed it up the ridge is still acting on it. The direction in which the force now acts on the stone is such that it no longer tends to prevent it falling; and further, supposing it was directly opposed to its motion, it would have but little effect against the steep slope of the side. Now draw the contour lines of this mountain. It will be found that they exactly correspond to the isothermal lines round the hot wire placed between the cold plates. The dust and the stone each fall towards the side, because that is the direction of steepest slope.

General Remarks.

This tendency which the dust in our atmosphere has to move away from hot bodies, and attach itself to cold ones, will, I have no doubt, help to explain many phenomena which are not at present well understood. No doubt, many things will suggest themselves to different minds as receiving their explanation in this somewhat curious liking of dust for lodging in cold places. Among other things, it explains the reason why stove and hot-air heated rooms are always so much dirtier than those warmed by open fires. In a stove-heated room the air is warmer than the walls and than the objects in the room, the dust therefore tends to leave the air, and to deposit itself on every object colder than itself in the room; whereas, in a room warmed with an open fire, the heating being principally done by radiation, the walls and furniture are hotter than the air, they therefore tend to throw off the dust, and even when it does fall on them, it does not adhere with that firmness with which it does to a cold surface, and any breath of air easily removes it.

Diffusion also, no doubt, plays some part in determining whether dust shall or shall not adhere to the walls and ceilings of rooms.

Again, a knowledge of this tendency of dust to settle on cold surfaces is necessary to enable us fully to explain why so much soot adheres to the inside surfaces of chimneys. If the smoke were cold, so much soot would not settle in the chimneys, nor would it adhere so firmly.

A simple experiment to illustrate this tendency of dust to leave warm, and

to settle on cold surfaces, is made in the following way:—Take two narrow strips of glass mirror, any substance will do, but the mirror surface shows the result best. Arrange so as to hold these strips of glass face to face, and with their surfaces at a distance of a few millimetres, but before putting them in their places, heat one of them to a temperature of say 100° C. Have ready a tall glass vessel, large enough for the glass strips to enter freely. Now fill this vessel with some dust, by burning sodium or magnesium, or by shaking up some calcined magnesia or other powder. By the time the air in the vessel is settled and cooled, but before the dust settles, have ready the glass strips, one of them hot as directed, and placed in front of the other, face to face, with an air space between. Now put the mirrors into the vessel among the dust. After a minute or so examine them. The following will be the result. The hot one will be quite clean, while the cold one will be white with dust. That the dust has no tendency to settle on the cold one, may be proved by putting at the same time in the vessel another cold strip some distance from the hot one, when it will be seen that this one is almost entirely free from dust, depending upon whether it was a little hotter or colder than the dusty air.

When one looks at the enormous amount of dust deposited on the cold mirror in this experiment, we cannot help associating the result in some way with the condensation of vapours, and it takes some time before we can arrange our ideas and realise that the thick white deposit was truly thrown out of suspension and settled on the mirror in the solid state, and was not in the state of vapour before coming into contact with the cold glass.

A somewhat curious experiment may be made with light calcined magnesia powder, which shows the action of this force in a marked way. The magnesia is heated to a good red heat in an iron vessel. If we now take a metal rod 5 or 10 mm. diameter and heat it as hot as the powder. We may then dip in into the powder, and stir it as much as we please, but on taking the rod out, it will be found to be quite clean. But if the rod is cold, it comes out of the powder with a club-shaped mass of magnesia adhering to it, so thick that the magnesia-coated end is twice as thick as the rod itself. If the rod is kept in the hot powder for a short time, and then taken out, with its coating of powder adhering to it, whenever the powder gets outside the hot vessel, and exposed to the cold, it falls away, as the inside of the powder is now hotter than the outside.

Most of us have noticed when heating powders, particularly if they are light, that while they are heating they take on a peculiar semi-fluid appearance if stirred, or if the vessel is tilted back and forwards. This I have always supposed was due to the escape of occluded gases from the powder, keeping it in a state of semi-suspension. Now, however, I think this peculiar effect is a result of the repulsion due to heating. My reason for supposing this

is, that if after the powder is heated it is cooled quickly, and again heated before there is time for it to absorb gases, the same semi-fluid appearance is again produced while heating. Further, if the powder, instead of being heated in a closed vessel, is placed in a cup, so that the under side of the powder is kept hot, while the top is cooled by radiation, so long as these conditions are kept up the powder retains its fluid-like properties, moving about on the slightest tilting of the cup, and conducting itself in a way very suggestive of the spheroidal condition, but without any generation of vapour to give rise to the irregular movements seen in liquids. It seems possible that something of the spheroidal condition may receive its explanation in this repulsion between hot and cold surfaces. This repulsion may be illustrated by placing a hot and a cold surface together. A piece of cold glass, for instance, slides about in a remarkably easy way on a hot surface of glass.

Many practical applications of this attraction and repulsion will no doubt be found. It might be easily applied to the condensation of those fumes from chemical works which at present are allowed to pollute the air. But perhaps the application of most general interest would be towards the prevention of smoke, or rather the prevention of the escape of smoke into the atmosphere. Whatever interest, however, it may have in this way, it is clear it can never meet with general adoption, save under compulsion, as it will effect no saving in fuel, such as would result from more perfect forms of combustion.

I have, however, made some experiments in this direction, and find that by placing a tall metal chimney over a very smoky paraffin lamp, surrounding this chimney with another tube slightly larger, and causing the products of combustion to rise up the centre tube, and descend through the annular space between the two tubes, the soot is all taken out, and nothing but a white vapour is seen escaping. On examining the tubes after they have been in use some time, the inside surface of the inner one is found to be slightly coated with soot, while its outer surface is perfectly clean and bright, not a speck of dust on it, and the inside of the outer tube, which is only a short distance from it, is thickly coated with soot. This arrangement, however, is too complicated, save for special purposes.

It has been already stated that the reason why so much soot collects in chimneys is that the gases are hotter than the sides of the chimney. In cases where the gases are allowed to escape at a high temperature advantage might be taken of this tendency. If we simply cooled the smoke in the presence of plenty of depositing surface, much of its soot would be trapped out, and the escaping smoke made less dense. The amount that might be trapped in this way will depend on the extent to which the gases could be cooled.

For works with large chimneys this plan evidently could not be adopted, and in their case the purification would require to be down at the bottom of the

chimney. The evident objection to this is, that as the gases are cooled in the depositer, the draught in the chimney will be destroyed. This, however, can be avoided by the use of "regenerators." The impure air would be led to a cold regenerator, where it would be cooled and its impurities deposited; and when purified it would be led through another chamber, where it would be heated before being sent up the chimney. This arrangement would not require heat to be spent in working it, as the process would be reversed, and by simply reversing the direction of currents from time to time the heat stored up in cooling would be used for heating the purified gases before being sent up the chimney. This purifying process by heating and cooling would require to be done a number of times, and the air sent through a succession of regenerators before it could be made perfectly pure.



Fig. 1



Fig. 2

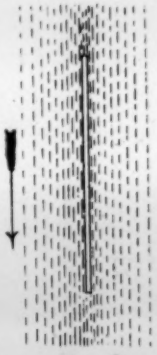


Fig. 3

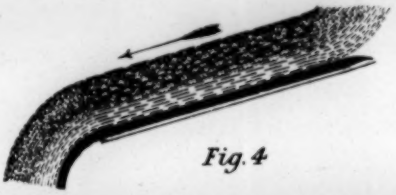


Fig. 4

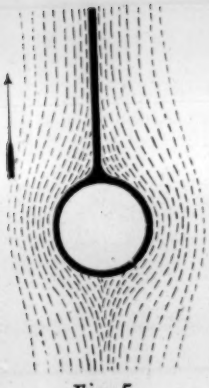


Fig. 5



Fig. 6

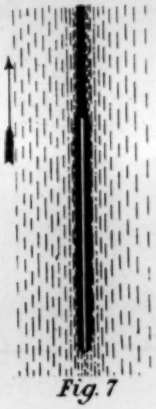


Fig. 7

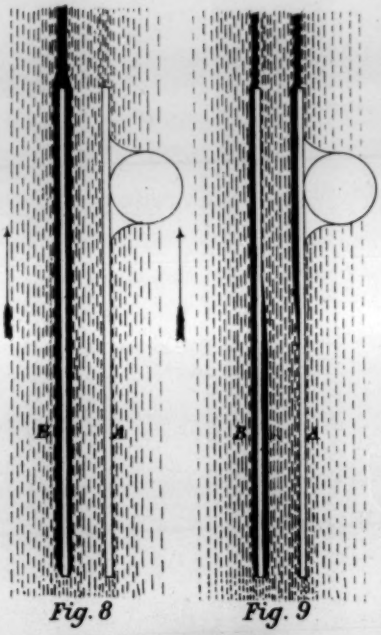


Fig. 8 Fig. 9

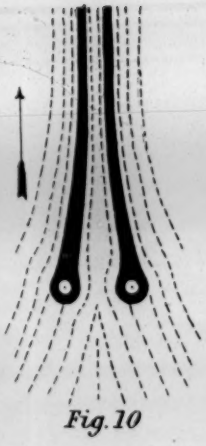


Fig. 10

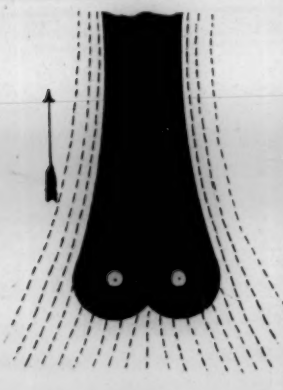


Fig. 11

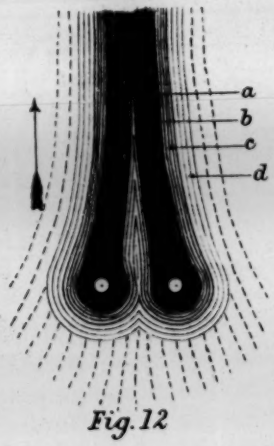


Fig. 12

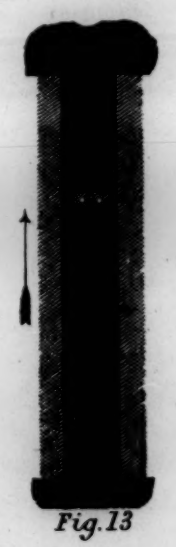


Fig. 13



Fig. 14



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XVI.—*On* Stichocotyle Nephropis, *a new Trematode.* By J. T. Cunningham, B.A., Fellow of University College, Oxford, and Naturalist in charge of the Marine Station, Granton, Edinburgh. (Plate XXXIX.)

(Read 5th May 1884.)

The Norway lobster, *Nephrops norvegicus*, on account of its abundance in the Firth of Forth, and the consequent ease with which it can be obtained from the Newhaven market, is given to the practical classes in the Natural History Laboratory of Edinburgh University for dissection, as an example of the decapodous Crustacea. One day in December last, while I was superintending the work of a class engaged in the study of this animal, one of the students, whose name I have unfortunately forgotten, called my attention to some globular protuberances on the intestine of the specimen he was dissecting. At the time I was unable to answer his questions any further than to say that the protuberances were the cysts of a parasite, and I put the specimen by for subsequent examination. On opening the cysts afterwards I found in them a small white worm, which proved to be a Trematode possessing novel characteristics. In the following paper I shall describe this parasite, and show that it is so distinct from all Trematodes hitherto known as to constitute a new genus. On several occasions I had the pleasure of examining the animal in the company of my friend and former colleague, Mr Duncan Matthews, and some of the points in its structure were first noticed by him.

I will first describe the animal as completely as possible, and then deal with the manner of its occurrence and its relation to other Trematodes.

The worms when taken out of the cysts are elongated and cylindrical in shape, one surface, the ventral, being slightly flattened; they vary in length from ·75 mm. to 8·0 mm. They are white in colour and somewhat opaque, so that there is considerable difficulty in making out their internal anatomy under the microscope. The body tapers towards each end, the thickest part being near to the oral or anterior extremity. The arrangement of the organs is bilaterally symmetrical. The mouth is a small simple circular aperture, situated on the ventral surface, close to the anterior end of the body. Behind it, along the median line of the ventral surface, is a single row of large muscular suckers, which diminish gradually in size towards the posterior end. The margins of the mouth are muscular, and its cavity can be dilated and contracted, so as to act as an additional sucker. When the animal is viewed with its ventral surface upwards, slightly compressed by a cover-glass, and under a

low power, it presents the appearance shown in Plate XXXIX. fig. 1. The ventral series of suckers is seen along the median line; each of them has a central depression varying in size according to the state of contraction, and round this is the projecting rim, in which can be seen the radiating muscles by which the sucker is dilated. The number of suckers present varies in different individuals according to their age and size,—the smallest specimens, such as the one shown in fig. 4, may have as few as 7, the larger usually have 15 or 16, while in the largest I have counted as many as 22. No doubt specimens might be found the totals of whose suckers would supply all the intermediate numbers between these.

The suckers are always more difficult to distinguish at the posterior end of the series, where they are very small, and they evidently increase in number at this end, just as the segments of a Chaltopod. It is this approach to metamerism which renders the creature specially interesting. The metamerism, however, does not extend to any of the other organ systems, and consequently the animal cannot claim among the Trematodes so isolated a position as the *Gunda segmentata*, described by LANG, among the Turbellarians. From the disposition of the system of suckers, I have named the animal Stichocotyle, adding Nephropis for the specific name, from the name of its host.

The surface of the body is marked by closely set transverse folds, which are indicated in fig. 1, between the suckers. These folds, seen in optical section, give the body a crenated outline, which is also indicated in the figure. When the body is much extended, either by compression or by the muscular movements of the animal, the folds disappear; they are probably due to the presence of an inelastic cuticle, although neither in the opticle nor actual section of the integument can a separation between cuticle and epidermis be distinguished. The external layer of the body wall, as seen in optical section in the living animal, is homogeneous and transparent, and of considerable thickness.

The most conspicuous of the internal organs are the main canals of the water-vessel, or excretory, system. These are two in number, one running down each side of the body through its whole length. Their size, in comparison with that of the whole animal, is extremely large; their walls are thrown into transverse folds. The interior of the canals is crowded with large spherical concretions similar to those found in the excretory system of other Trematodes and of Cestodes. These concretions, during the examination of the living animal, are continually moving with considerable rapidity, the contractions of the body forcing them suddenly from one part of the canal to another. In the middle line, between the main excretory canals, is the intestine. From the mouth can be traced a narrow œsophagus, dilating into a muscular pharynx, with thick walls, and this leads into an intestine which diminishes slightly in

diameter towards the posterior end, where it ends blindly. The intestine is quite simple, and has no branches or diverticula.

When a specimen is examined with its dorsal side upwards, and considerably compressed, the intestine and lateral excretory canals are seen with great distinctness, as there are no muscular thickenings dorsally to form suckers. Fig. 2 shows somewhat diagrammatically the view thus obtained. At the posterior end the two lateral canals terminate in muscular portions, which pass inwards behind the intestine, and unite to form a single median chamber with thick muscular walls. This chamber opens in the usual way by a pore on the dorsal surface, close to the end of the body. The rhythmical dilatation and contraction of the terminal chamber is very pronounced, and it commonly happens, when the animal is under compression, that one of the spherical bodies contained in the lateral canals passes into the terminal chamber, and is expelled from the dorsal pore with some force. The appearance of the terminal part of the excretory system under a high power is shown in fig. 3.

When the living animal is very attentively examined with an objective of high power, by careful focussing fine ciliated canals can be made out between the large lateral canals and the dorsal surface. It is probable that, like the corresponding fine canals in other Trematodes, these open into the main lateral canals, and are, on the other hand, in communication with the intercellular spaces of the body-parenchyma; but owing to the opacity of the tissues, I have not yet succeeded in tracing out these relations. The cilia, whose motion alone enables one to trace the tubules in question, are of great length, and are situated on the walls of the tubules at intervals. I have not been able to discover any "éntonnoirs ciliés" at the ends of the branches of the system of tubules, like those described by FRAIPONT.* I have followed the ciliated tubules sometimes for considerable distances. Their course is somewhat irregular, but maintains a longitudinal direction. They branch occasionally, but the branches never extend into the median region of the body above the intestine. I have not found any tubules on the ventral side of the body, but they extend forwards beyond the anterior limit of the main lateral canals.

I have now described the general disposition of the digestive, excretory, and integumentary systems of the animal, and have hitherto mentioned nothing which cannot be made out in living specimens. No reference has been made to the generative or nervous systems. In the stage of the animal's history which is passed within the body of Nephrops neither of these systems is developed. I shall refer to structures which may be their rudiments. Special sense organs are altogether absent.

In order to examine the histological structure of the tissues, I have pre-

* "Rech. sur l'appareil excréteur des Trém. et Cestoides," JULIEN FRAIPONT, *Arc. de Biologie*, Tom. i. 1880.

pared transverse sections in continuous series from specimens preserved with picro-sulphuric acid, and stained with borax-carmine. The specimens chosen for this purpose were of the medium size, carrying about 16 suckers. The sections are all very similar to one another, differing chiefly in the relation which they bear to the series of suckers. In one taken from the middle of the series, the intestine is seen in the centre, elliptical in outline, the long axis of the ellipse being dorso-ventral. The epithelium of the intestine is thick, and composed of large nucleated cells, which form sometimes more than one layer, and are not quite regular in arrangement. Both in the living animal and the prepared section it can be seen that the cells of the intestinal epithelium are rapidly proliferating; the free ends of the cells project into the lumen in various degrees, and a number of detached cells are seen lying free in the interior. In the living animal these cells float about under the influence of the movements of the body, and are occasionally expelled from the mouth. Some of them contain minute round granules.

On each side of the intestine is the section of one of the main lateral excretory canals, in which there is no distinct epithelium to be seen. There are nuclei in the walls, and the cavity may be lined by an epithelium of extremely thin cells, to which these nuclei belong. The walls of the canal are extremely thin.

The parenchyma of the body, or mesenchyma, appears in the sections as a fine reticulum with deeply stained nuclei at the nodes. The actual structure of the mesenchyma in Trematodes has been much disputed,* some observers maintaining that the intercellular spaces are globular and the cells stellate; others, *vice versa*, that the cells are globular, and the intercellular spaces reticulate. In the living Stichocotyle the mesenchyma is seen to be crowded with minute bright refringent granules, which seem to be contained in intercellular spaces, as they move through considerable distances in parts of the animal which are in active contraction. They are shown in fig. 3.

The muscular layers of the body wall are imperfectly differentiated; they are represented by a zone of closely crowded nuclei at the periphery of the mesenchyma, and, external to this, a zone of small dots, which are probably the sections of longitudinal fibrils. The account of the muscular layers of the integument in the young of Amphilina, given by Salensky,† agrees pretty closely with the state of things in my sections, except that he mentions nuclei in the external of the two layers, and in the zone of dots I have described there are no nuclei.

The sucker is composed chiefly of elongated cells, whose long axis is perpendicular to the epidermis. These are simple muscular cells which dilate the

* *Vide* Fraipont, *loc. cit.*, p. 428.

† *Zeit. f. wis. Zool.*, Bd. xxiv., 1874.

cavity of the sucker. Nuclei are scattered through the tissue, each cell probably possessing one. The muscles which contract the cavity of the sucker are not so conspicuous. The tissue of the sucker is separated from the tissues of the body by a thin limiting membrane, which is continuous at its periphery with the limiting membrane of the epidermis. This is an arrangement which is not easily explained, as, the muscles of the sucker being probably a specialisation of the ordinary muscles of the body wall, it would be expected that the continuity between the two would be maintained.

Beneath the lateral excretory canal of the right side, in the anterior sections, is an area occupied by very closely crowded nuclei. This can be traced through successive sections of the series as far as the end of the fifth sucker. It passes from its first position, under the right main canal, to the left side of the same canal, at the same time becoming thicker, and towards its termination becomes so broad as to extend beneath the intestine from the right canal to the left. There is thus an irregular cord of small unmodified cells extending through a considerable part of the length of the body, and it is possible that the generative organs of the adult are derived from this.

The most external layer of the body representing the epidermis and cuticle, is in sections, as in the living animal, quite homogeneous. I have not yet been able to distinguish in it either nuclei or cell boundaries, or a separation between epidermis and cuticle. The layer becomes thinner where it lines the cavity of the sucker. In the living animal small funnel-shaped openings are seen in the epidermis, which may be the apertures of glands, but as they are not visible in the sections it is possible that they are only fractures produced by compression.

The only trace of tissue which may belong to the nervous system is a tract composed of very fine fibrils in some of the sections anterior to the mouth. This tract forms a band extending horizontally across the body near to the dorsal side. The fibrils of which it is composed are extremely minute, and the whole tract is destitute of nuclei. It is shown in fig. 6, and may represent the cerebral ganglion. A pair of processes from this mass of tissue can be traced through the succeeding two or three sections, which are probably the rudiments of a pair of lateral nerve-cords. They pass downwards towards the under side of the main excretory canals.

The cysts in which the animal occurs are scattered on the extremely thin walls of the posterior part of the intestine of Nephrops, in the region of the abdomen. They sometimes contain more than one worm, as many as six having been taken by Mr MATTHEWS on one occasion from a single cyst. Usually the wall of the cyst is soft and opaque, and white or light yellow in colour. It is of a cellular nature, and is apparently a pathological product of the tissue of the intestine of the host.

The cysts vary in size with the age and size of the worm within, and the youngest and smallest ones are brittle and dark brown in colour. A very young worm taken from such a cyst is shown in fig. 4. It has only seven suckers. The worm in all cases, when placed on a slide in a little water, exhibits movements of contraction and extension, and coils or straightens its body, but is not able to travel over much space. When an infected crayfish is opened which has been twenty-four hours out of water, the worms are often found to have escaped from the cyst, and are found lying on the muscles; but I think this does not take place while the Nephrops is living. The number of cysts varies considerably. I have sometimes found them covering the posterior part of the intestine completely; and in other cases only two or three of the very smallest brown cysts were present. The diameter of the cysts varies from ·5 mm. to 2 or 3 mm. I have taken as many as forty worms from a single Nephrops.

The proportion of specimens of Nephrops infected is not small. In one case I found three out of eight contained the parasite. Usually out of a dozen opened three or four are infected; but sometimes a dozen may be searched without a single parasite being found. My observations have extended now over nearly four months, and I have not yet found any variations in the state of the parasite.

I have not found the parasite in any other part of the body of Nephrops except the intestine; and I have no evidence to show whence it is derived, what is its mature state, or in what conditions its adult stage is passed.

It seems probable that the eggs are taken into the stomach of Nephrops with its food, and that an embryo escapes from the egg, which pierces the wall of the intestine, and there develops into the stage of the worm which I have examined. The further development most likely takes place in the body of some large fish which feeds on Nephrops; but hitherto no Trematode is known living inside the body of a marine fish except the *Calicotyle Kroyeri*, which is found in the cloaca of rays, and *Encotyllabe Pagelli* in the mouth of *Pagellus centrodontus*.*

In passing on to consider the affinities of the parasite, it may be set down as obvious that it is in every respect a typical Trematode. The characters of the water-vessel system and of the suckers could not be found outside that class. But the arrangement of the suckers is entirely novel. A serial arrangement of the suckers is not uncommon among Trematodes; but there is no other genus in which they form a single series extending along the median ventral line through nearly the whole length of the body. The series when present is usually double. Microcotyle† has in the posterior third of its body

* Van Beneden et Hesse, *Mém. Acad. Roy. de Belg.*, Tom. xxxiv.

† *Ibid.*

a series of small suckers on each side. They are very numerous, and all of the same size. In Octocotyle * there are, near the aboral extremity, four pairs of lateral suckers, one pair behind the other. The suckers of Gastrocotyle † form a single series along the edge of a projecting membrane on the right side of the body. Ernst Zeller describes a serial repetition of pairs of suckers as an occasional abnormality in Diporpa. ‡ At the posterior extremity of this genus there is a pair of large suckers forming divergent projections. Zeller met with a specimen in which the single pair was replaced by three pairs, one behind the other. In all these cases the suckers are provided with chitinous hooks, as in nearly all the Polystomidæ. Stichocotyle is without chitinous armatures in any part of its body. Until the adult form is found and its anatomy examined, it is impossible to say anything more definite about the position of Stichocotyle than that it belongs to the Polystomidæ, though it differs from all other Polystomidæ in passing through an encysted stage within the body of another animal.

I hope before long to trace out the whole life history of this interesting form, as at the Granton Marine Station I shall have good opportunities for carrying on the search after its earlier and later stages. In concluding the present account I have to express my warmest thanks to Dr Arnold Lang, of the Naples Zoological Station, who kindly sent me some valuable suggestions and references.

EXPLANATION OF PLATE XXXIX.

Letters of Reference.

bls.	Cord of blastema.
ci. ca.	Ciliated tubules of water-vessel system.
co.	Spherical concretions in lateral canals.
ep.	Epidermis and cuticle.
e. ap.	External aperture of water-vessel system.
f. ce.	Free cells in lumen of intestine.
gl.	Openings of dermal glands (?).
int.	Intestine.
int. ep.	Epithelium of intestine.
l. ca.	Lateral canals of water-vessel system.
me.	Mesenchyma.
mu. su.	Muscles of sucker.
m.	Mouth.
me. gr.	Granules in mesenchyma.
ne.	Cerebral ganglion.
ph.	Pharynx.
su.	Series of suckers.
te. ch.	Terminal chamber of water-vessel system.

* Van Beneden et Hesse, *Mém. Acad. Roy. de Belg.*, Tom. xxxiv.

† *Ibid.*

‡ *Zeits. f. wiss. Zool.*, Bd. xxii. 1872.

Figs. 1, 2, 3, 4 were drawn from fresh specimens. All were drawn without the aid of a camera lucida.

Fig. 1. Ventral view of Stichocotyle, as seen under slight pressure.
Fig. 2. Optical section of the whole animal, seen with dorsal surface upwards.
Fig. 3. Optical section, showing termination of water-vessel system.
Fig. 4. Very young specimen, with seven suckers.
Fig. 5. Transverse section, passing through middle of first sucker of moderate-sized specimen.
Fig. 6. Section through pre-oral region of same specimen.

The fractions represent the relation of the diameter of the drawing to that of the object.

Fig. 1.
40/1

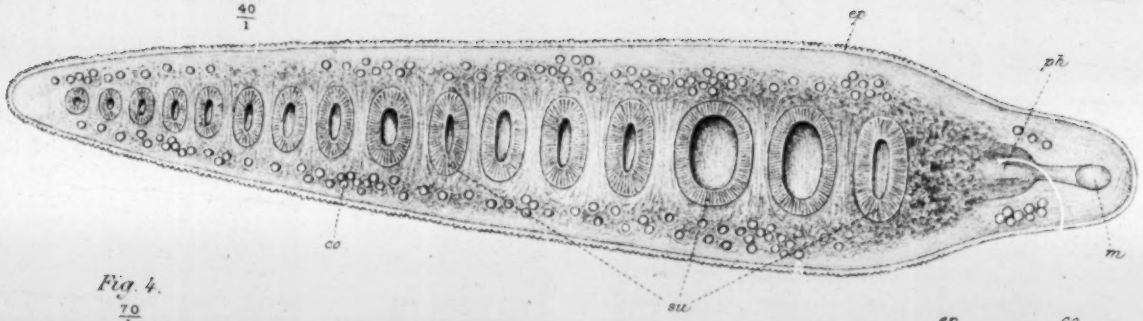


Fig. 4.
70/1

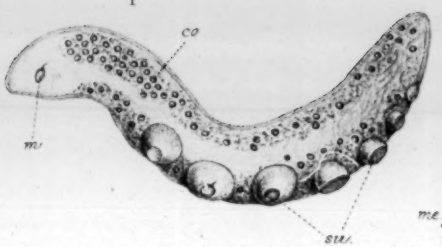


Fig. 3.
166/1

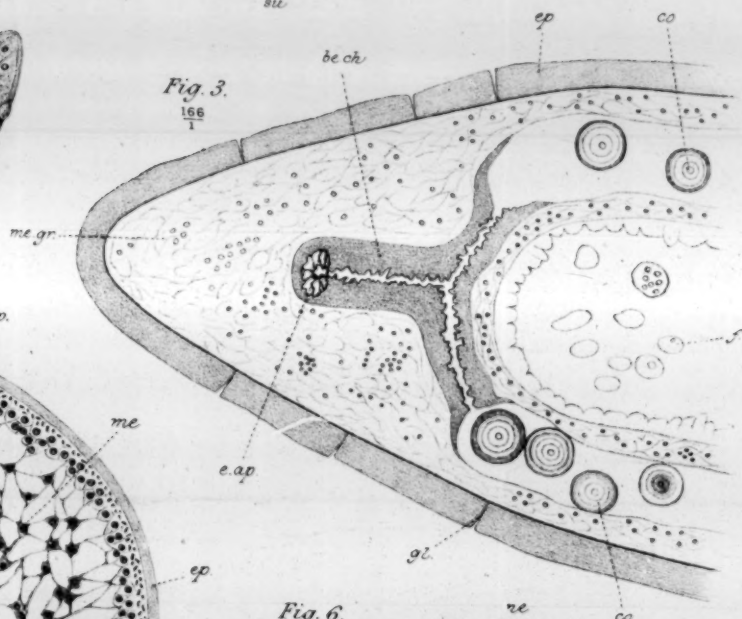


Fig. 5.
160/1

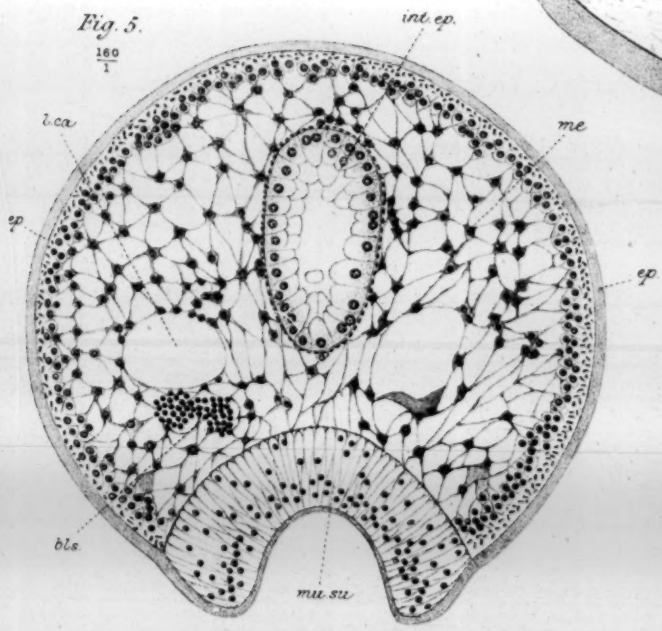


Fig. 6.
190/1

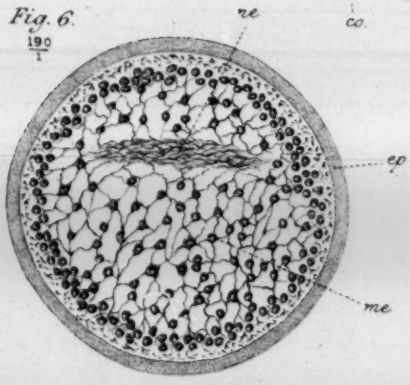
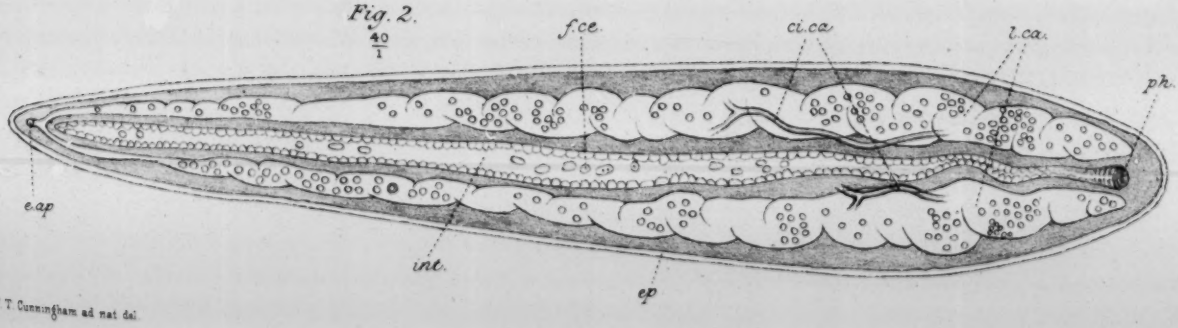


Fig. 2.
40/1



J. T. Cunningham ad nat. del.

F. Huth, Lithᵗ Edinᵗ

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XVII.—*The Enumeration, Description, and Construction of Knots of Fewer than Ten Crossings.* By Rev. Thomas P. Kirkman, M.A., F.R.S. (Plates XL.–XLIII.)

(Read June 2, 1884.)

1. By a knot of n crossings, I understand a reticulation of any number of meshes of two or more edges, whose summits, all tessaraces (ἀκή), are each a single crossing, as when you cross your forefingers straight or slightly curved, so as not to link them, and such meshes that every thread is either seen, when the projection of the knot with its n crossings and no more is drawn in double lines, or conceived by the reader of its course when drawn in single line, to pass alternately under and over the threads to which it comes at successive crossings.

The rule for reading such a reticulation of single lines meeting in tessaraces only is this—Coming by the edge or thread pq to the tessarace q, you leave it by the edge of q which makes no angle with pq, nor is part of thread under or over which you pass at q.

2. It is not necessary, after what Professor Tait has written on knots, to prove that every reticulation having only tessarace summits, whether polyedron* or not, if it be one continuous figure and projected to show all its crossings and no more, can be read all through by this alternate under and over, so that all its closed circles, one or more, can be written down in numbered summits, and that the knot can be labelled as unifilar, bifilar, or trifilar, &c.

3. If a thread a of a knot, after passing under or over a thread b, passes over or under b before it meets a third thread c, there is a linkage of two crossings and a *flap* between them. This flap is the small eyelet seen between two links of a slack chain as it lies on the table: it is a 2-gon, a mesh of two edges and of two crossings. Here see art. 9.

4. In our enumeration of knots of n crossings, two, C and C′, are counted as the same one, whenever and only when, in the number, polygonal rank, and order of their meshes C′ is either the exact repetition or the mirrored image of C; and I consider the threads of all the circles of a knot to be tape untwisted.

5. Nothing general seems to have been written upon knots of more than seven crossings. Nor, fortunately for the claims of those knots upon the inte-

* I hope to be pardoned for omitting the *h*. It annoys me to hear the learned say *polyhēdron*. Why not *perihodic* also? or, more learnedly, *perihōdic*?

rested attention of the student, has unanimity been even so far secured. In what LISTING and TAIT have contributed to this theory, there is an affirmation of identity, or of equivalence, denoted by the symbol =, between two knots of seven crossings which, by the above definition of sameness, are as unlike as they can be. This, of course, is due to a mere difference in definitions. The right definition in the view of LISTING and TAIT I find not easy to seize, and I cannot work on reticulations between equivalence and identity, nor pause to consider the deformations of a knot A into an equivalent knot B that can be effected by twisting the tape of A. I content myself by exhausting the forms that differ according to my definition; and I leave to a more competent hand the reductions to be made by twisting.

6. The reader will judge for himself whether the number of different unifilar knots of seven crossings is twelve, as I am compelled to believe, or at most eight, as TAIT prefers to say. Whatever be the decision of the reader, I am highly delighted, while attempting to write on a theme so dry and tiresome, that we have, at the outset, such a pretty little quarrel as it stands wherewith to allure his attention.

7. Every polyedron which is an n-acron having only tessarace summits is a *solid* knot of n crossings, on which is neither linkage nor flap. Such a knot can be projected on any of its triangular or m-gonal faces, so as to show all its n crossings, and no more, within that face or at its summits. It has no linear section, *i.e.*, no plane can cut it in space, nor can any closed curve be drawn upon lines of its projection, without meeting it in more than two points, on edge or at crossing.

In a knot which is no polyedron, we call a section that meets it in only two projected summits or crossings, *linear*, as passing through two points only of the figure; although no crossing of a mesh in space can be cut through its opposite angles without making four ends.

8. No projected knot, solid or unsolid, can have a linear section through one edge kl only, and through one crossing q only. For, if it can, let the two threads at q on the left hand of the section be pq and rq, pq passing over rq at q; then pq at the crossing p passed under a thread, and rq at r passed over one. Cut at q, making four ends; reunite into one thread rp the two ends on the left; this shortened thread passes over a thread at r and under one at p, as before, and its further course is unaltered in either direction. The same is true of the shortened thread made by reuniting the two threads on the right of the section.

The figure is now the projection of a knot of $n-1$ crossings having two portions, L on the left and R on the right, which are connected by a single thread kl, the law of under and over being observed in both L and R. The course of the thread kl, pursued along its circle small or great through R

from k upon R, must bring it back to l upon L through L. But this is clearly impossible from want of a second connecting thread; which proves the proposition.

9. *Knots Solid, Subsolid, and Unsolid.*—A solid knot is a polyedron, art. 7.

Subsolid knots admit of no linear section but through the two crossings of a flap; through the projections of these a closed curve can be drawn meeting the knot in no third point.

The projections of an unsolid knot admit one or more linear sections either through two crossings not on a flap, or through two edges coming from two crossings *not on the same flap.*

If a projected unsolid V admits a linear section through two edges coming from two crossings on the same flap, V is made up of two portions, K and L, connected like two links of an ordinary chain, so that K (or L) can be set free in its completeness by breaking only one thread of the other. No knot V constructed in these pages is such a compound of K and L. Such a compound is easily drawn; in such a V either K or L can be slipped along the thread of the other, without twisting a tape, so as to occupy, if the other be unifilar, any position upon it. All our unsolids are composite; but no severing of a single thread will ever set free on one of them a portion which is a complete knot.

Of solid knots we are not treating. If the apparent dignity of knots so maintains itself as to make a treatise on these n-acra desirable, it will be no difficult thing to show in a future memoir how to enumerate and construct them to any value of n without omission or repetition. The beginner can amuse himself with the regular 8-edron, which is trifilar, or with the unifilar of eight crossings made by drawing within a square a square askew, and filling up with eight triangles.

10. I consider a knot as given by its projection upon and within any one, 2-gonal or m-gonal, of its meshes drawn large, and as having the symmetry of that projection. Nor do I trouble myself with inquiring how far that symmetry is affected by the law of under and over at the crossings, because, in reading the circle or circles of a projected knot, we can take any crossing q as our first, and can on beginning to read take either of the threads at q as passing under and over the other. A knot in space can be read only as given.

In my description of the symmetry of our reticulations, I shall assume that the reader understands the terms employed. They, with others not wanted here, are necessary and sufficient; they are the only such terms that ever have been proposed; and, for more than twenty years since they were introduced, no more suitable terms have offered in their stead. I am quite ready to use better ones when they are invented. The symmetry, however, of the figures handled in this paper is of itself so evident that the reader will easily satisfy

himself, without debate about the terms employed, as to the truth or error of my enumerations.

11. All that we need to add here is on the symmetry of flaps, which are 2-gons, correctly drawn as two curved lines through the same two points.

A flap has the symmetry of its undrawn diagonal d through its two crossings, and may be conceived as standing symmetrically about d, in either of two planes at right angles to each other, which contain d. This d may be asymmetric, or epizonal, or zonal, or zoned polar, or zoneless polar; and the flap is accordingly asymmetric, or epizonal, &c. The two edges of a flap are unlike only when it is asymmetric or epizonal.

In a zonal flap, a single zonal trace passes through the two crossings; in an epizonal flap, a single zone passes between the crossings. In a zoned polar flap, two zonal traces intersect in the centre, the termination of the 2-zoned axis.

In the centre of a zoneless polar flap, an axis of 2-ple repetition terminates.

${}_3$A and ${}_4$A have each one zoned polar flap.
${}_5$A has one epizonal flap.
${}_6$F has one epizonal and one asymmetric flap.
${}_6$G has two different polar, and one zonal flap.
${}_6$H has one zonal flap and no other.
${}_8$S and ${}_8$Q have each one zoneless polar and one asymmetric flap; so has ${}_8$Aj.
${}_8$Ak has one asymmetric flap and no more.
${}_8$Am has one zoned polar flap and none other—art. 45.
${}_8$Bn has one epizonal, two zonal, and one asymmetric flap.
${}_8$Bq has one zoned polar and one asymmetric flap.
${}_8$Bu has three zonal flaps only.
${}_8$Bv and ${}_8$Bw have each one epizonal and two asymmetric flaps.
${}_8$By has one zoned polar and one zonal flap.

12. The construction of polyedra and of other reticulations of n summits is best apprehended by studying their reduction by fixed rules to antecedents or bases of $n-i$ summits. We proceed to the reduction of knots.

Reduction of an Unsolid Knot Q *of* n *Crossings.*

In this are two processes,—the clearing away of concurrences, and the removal of least marginal subsolids.

13. *Concurrences.*—Two or more continuous flaps, each having a crossing common to the next, are a concurrence of two or more, except when two or three flaps are collateral with the same triangular mesh. Three such flaps on a triangle complete the irreducible subsolid ${}_3$A; and two on a triangle are not counted a concurrence.

When a concurrence of n stands about the $(n+k+2)$-gonal mesh F, their common collateral, F is reduced by deletion of $n-1$ flaps, each conceived to vanish by the union of its two summits, to the $(k+3)$-gon F′, carrying one only of those flaps.

If their collateral F is an $(n+1)$-gon, it is reduced by the vanishing of $n-2$ of the concurrent flaps to a triangle f carrying the remaining two. This f cannot lose a flap without losing an edge and disappearing.

Every concurrence on the unsolid Q of art. 12, whether standing on a marginal or non-marginal component of Q, is to be thus reduced, and Q now becomes an unsolid Q′ without a concurrence, of $n-i$ crossings.

14. *Least Marginal Sections and Least Marginal Subsolids.*—Our unsolid Q′, obtained by deletion of i flaps, has one or more *linear sections*, marginal or not.

By a marginal linear section of Q′ can be cut away one and only one marginal subsolid, on which (art. 9) lies no linear section except through the two crossings of a flap.

By a *least marginal section* of Q′ can be cut away a *least marginal subsolid.*

A marginal subsolid of k crossings all untouched by any possible least section, is a least marginal, when no marginal subsolid of fewer than k crossings untouched by the section can be cut away from Q′ by any kind of section.

15. *The Five Kinds of Linear Section of an Unsolid Knot.*—These are,

ffc, which is read, flap on flap close;
ff, " " flap on flap;
fe, " " flap on edge;
ef, " " edge on flap;
ee, " " edge on edge.

The first letter in these symbols denotes the flap or edge of the least marginal subsolid cut away from, or in construction imposed on, the unsolid or subsolid charged.

16. The linear section *ffc* is the only one that passes through two crossings. After making the section *ffc*, there is a pair of truncated crossings, both on the diminished Q′ and on the subsolid removed. These are completed into tessaraces in the severed portions by replacing each portion on the other by the two pairs of edges of two flaps, at the cost of which two flaps the portions were, in construction at the section *ffc*, united to form Q′.

These pairs are conceived to be so united to the broken threads at the truncated crossings as to complete both the severed portions into two knots. This can always be done, and needs not trouble us, when we are reducing a projected figure of simple lines making tessaraces only.

If the subsolid S removed at this section *ffc* has, when completed by its restored flap, k crossings, the $n-i$ crossings of the undiminished Q′ are made fewer by $k-2$; for Q′ has lost only the crossings of S not on the section.

This S in construction of Q′ was counted as a least marginal charge of $k-2$ crossings. Two crossings are always lost when in construction a subsolid having k crossings is imposed at a section *ffc*.

In reduction at this section *ffc*, this S is a least marginal subsolid of $k-2$ crossings along with others of $k-2$ removed by any section *ff*, *fe*, &c.

17. Our unreduced Q′ of $n-i$ crossings may have in it every kind of least marginal section, art. 15. Such section, not *ffc*, always cuts two edges, making four ends. In every case, *ff*, *fe*, *ef*, or *ee*, those pairs of ends are conceived to be united on either hand into one edge, by which is restored the half-flap or the edge cut away in each portion when united by construction, in order that every summit should be a tessarace in the completed unsolid.

The imposition of a least marginal charge by *ffc* costs four edges of two flaps; by *ff*, *fe*, *ef*, or *ee* it costs only two edges, one on each of the united knots.

No crossing is lost when a charge is imposed by a section *ff*, *fe*, *ef*, or *ee*. All this will be found very clear and easy when we come to constructions, and examples will abound.

18. In this reduction of Q′ all least marginal subsolids, say of k crossings, are to be removed without regard to the number of their meshes, which may differ while each has added k crossings. And care is to be taken that none is cut away which has been loaded with another either on flap or edge, and thus made non-marginal.

When our Q′ is thus reduced, it has become Q_1 an unsolid of $n-j$ crossings ($j>i$).

This Q_1 will in general have one or more concurrences due to the flaps substituted for subsolids removed. All these are to be cleared away (art. 13), whereby Q_1 becomes Q_1', an unsolid without a concurrence; and Q_1' is to be treated as we treated Q′ in art. 14.

We shall finally arrive by these reductions either at an unsolid of two portions, neither of which is least, which is to be reduced by a final section to two subsolids each of c crossings; or at a ring of flaps which is reducible to the fundamental ${}_3A$; or to a nucleus subsolid or solid knot. We have now to set about the reduction of subsolids.

19. *Reduction of a Subsolid of* n *Crossings by its Leading Flap.*—The rule is—Remove both edges of a leading flap, or of a leading flap when there are co-leaders. By this removal, the two meshes covertical with the deleted flaps lose each a crossing; and if one or both coverticals are triangles, that one or both become flaps. The result obtained is a subsolid of $n-2$ crossings.

20. Every flap can be written AB,CD, where A and B ($A \gtrless B$) are collaterals, and C and D ($C \gtrless D$) are coverticals, of the flap.

We compare first the collaterals of the flaps whose leader is to be found.

If A_1B_1, A_2B_2, &c., are the pairs of collaterals, the leader has the greatest A, no matter what be the coverticals. If several flaps have the greatest A, the leader has the greatest B. If several have both A and B greatest, we compare coverticals. If one has the greatest C, it leads; if more than one, the greatest D gives the lead. If no leader can thus be determined, we have to examine the collaterals of the A's. The leader has more than any other of the greatest of these collaterals; and so on we go over the collaterals of the B's, the C's, and the D's. The leader, if there is only one, is certain to be found.

I have never had occasion to examine the collaterals of AB,CD. If two competitors have these all equal, it is almost a certainty that there is symmetry, and no leader, but a set of co-leaders. Where there is no symmetry, no two edges or flaps on a knot are alike.

It suffices, after writing two or more flaps as equally claiming by their AB, CD to lead, to place a note of interrogation, and to examine the symmetry, which readily betrays itself. The deletion of any one of the co-leaders completes the reduction.

A flap can neither be removed from a knot nor added to it without cutting of threads and reunion of ends. But this does not trouble us here, as by art. 2 we know that every projection making tessaraces only is a true knot, that its circles can be read by the rule of under and over, and that the threads of all the circles can be drawn in double lines as narrow untwisted tapes visibly passing under and over at alternate crossings.

21. In the converse problem of construction, the question is, in how many ways to add, on a knot P′ of $n-2$ crossings, a leading flap, so as to construct without risk of repetition a subsolid of n crossings. The note of interrogation written after the comparison of two flaps that can be drawn across two meshes of P′ is a presumption of symmetry, which is pretty certain to be verified when we come to draw in turn our new flaps on P′, and to examine the constructed P of n crossings as to the leadership of the doubted flap which turns P′ into P.

22. Two things are to be noted here, both in reduction and construction. If a flap f on any subsolid is covertical at its crossing a with a triangular mesh abc, which carries a flap f' on the edge bc, since abc cannot lose a crossing by the deletion of f, it thereby becomes itself a flap f'' collateral with the flap f'. Now a pair of collateral flaps is excluded from all our constructions, because it is a circle of two crossings, whose projection represents nothing in space but a movable ring through which one thread once passes. Wherefore the flap f is indelible or a *fixed flap*. It cannot be removed, nor be a competitor for the lead, either in reduction or construction.

When two flaps are collateral with the same triangular mesh, both are *fixed*; for the deletion of either leaves the other hanging by a nugatory crossing which admits a forbidden punctual section. The reader can easily verify this.

By continuing this reduction of a subsolid by removal of the leading flap, we must at last arrive either at a solid knot, or at one of the two irreducibles ${}_3$A and ${}_4$A, of three and of four crossings.

23. *Construction of Knots of* n *Crossings.*—The rules for this are the exact converse of those above given for reduction.

First, to construct the *subsolids* of n crossings, all inferior knots being given with their symmetry, we have in the first place to take in turn every subsolid P′ of $n-2$ crossings, and to determine before we draw them the different leading flaps that can be added on P′. Knowing its symmetry, we can write down and mark on its edges every different pair of points on flap or edge that can be joined as the crossings of a new flap, and also the collaterals and coverticals which this will have. We make a table of the possible leading flaps, with the notes of interrogation that presume symmetry in the P of n crossings to be built on P′. Next we draw the leading flaps, thus constructing and registering the resulting subsolids P.

A caution is required here, for the examination of the claim of a new flap, $ab=3$M, to leadership; a and b being the crossings of the flap, when one of its collaterals is a triangle *abc*. If c in this triangle is the crossing of a flap *cd*, *cd* becomes fixed (art. 22), for it is covertical with a triangle *cab*, which carries a flap on its edge *ab*. Care must be taken to exclude this flap *cd* from claim to leadership over *ab*.

I was caught in this trap in the art. 41, for I had entered the flap (*bd*) as led by (56), and thus missed the unifilar ${}_8$G. Professor TAIT found this knot, adding one to my first list of 8-fold knots. He first found also the unifilars ${}_9$A*l*, ${}_9$A*k*, and ${}_9$B*g*, omitted by a like error in arts. 51 and 56. He also first found ${}_9$D*m*, which I ought to have constructed along with ${}_9$D*l* in art. 61.

24. In the second place, we take in turn every unsolid P″ of $n-2$ crossings on which a leading flap or flaps can be drawn so as to abolish all concurrences, and to block linear section. Such leading flaps will be few. Next we draw them all, and thus complete without omission or repetition our list of subsolids P of n crossings. This list is the only difficulty of our work; what follows is for every value of n all easy routine, as we shall see; but it soon becomes too tedious by the enormous number of results to be registered and figured.

25. Next, to construct the *unsolids* of n crossings which have no concurrence, we impose in the first place on the solids and subsolids, and in the second on the unsolids, of $n-i$ crossings, each taken in turn as the subject Q′ to be charged, e charges of least marginal subsolids, all of k crossings, no matter what be the number of their meshes, so as to add to Q′ $ek=i$ crossings, completing an unsolid Q of n crossings without a concurrence.

The e charges may be all or none alike, or all but one alike, &c.; and from our list of subsolids of k crossings must be selected with or without repetition

every possible set of e charges. These, as well as their reflected images when required (although such images are neither registered or figured by us), have to be imposed in every different posture, by every kind of possible section, *ffc*, *ff*, &c., on every different set of e flaps or edges that can be selected on the subject knot, and in every different order that symmetry permits without repetition of results (art. 4), so that when the work is done not one of the unsolids Q of n crossings shall have a least marginal subsolid besides the e that we have just imposed, nor have a concurrence upon it.

26. The linear sections by which the charges are imposed may be any of the five of art. 15. But, observe, when we use the section *ffc*, we are to select the charge from our list of subsolids of $k+2$ crossings; because (art. 16) two will be lost. For other sections our selection of the charges will be from those of k crossings.

27. The number of different postures in which a charge can be imposed on Q′ depends on the symmetry of the united portions of the Q completed by the union. Let ϵ denote the edge or flap of the subject and ϵ' that of the charge in all the five sections *ffc*, *ff*, *fe*, *ef*, *ee*. The rules are three—

(1) If one or both of ϵ and ϵ' be zoned polar, only one configuration is possible by the union; no second and different (art. 4) can be formed by turning the charge C through two right angles about ϵ', nor by using C′, the reflected image of C, when C is not C′. Every knot on which is a zone is its own mirrored image.

(2) If neither ϵ nor ϵ' be zoned polar, and if they are not both asymmetric, two and two only different configurations can be made by the above variation of posture of the charge.

(3) If both ϵ and ϵ' are asymmetric, four different configurations can and must be made and registered, due to such variation.

No more results can be obtained by putting for Q′ the reflected image of Q′: nothing is so attainable but repetitions or reflected images of knots already registered.

On almost every subject Q′ and charge C, though having any symmetry, may be found asymmetric, *i.e.*, zoneless and non-polar, flaps and edges, which are to be dealt with by the above rules.

28. The subject Q′ to be charged with a set of least marginal subsolids may have or not have concurrences. All that is required in order that the completed Q shall have no concurrence, is that our number e of charges of k crossings shall be large enough to spoil all concurrences on Q′, as well as to cover at least once every marginal subsolid on Q′ which has fewer than $k+1$ crossings.

In the constructions of this paper, Q and C are one or both symmetric. When asymmetrics come to be handled both as subject and charge, the number

of results becomes unmanageably vast long before n the number of crossings is out of its *teens*.

29. The *final operation*, after construction of all knots of n crossings without concurrences, is to take every subsolid and unsolid R in our lists which has $n-c$ crossings and no concurrence, and to add to it in every possible different way c flaps making with one or more on R concurrences of every possible number of two or more flaps, thereby adding c crossings, and completing the number n. This last operation soon becomes impracticable from the number of results.

30. Nothing can be here added that will give so much insight into our subject as the actual construction of knots, to which we now proceed, first to that of subsolids, and next to that of unsolids of the number n in hand of crossings.

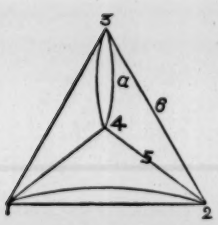
Two Fundamental Subsolid Knots.—The only subsolids that cannot be reduced by deletion of a leading flap (art. 19), are those of three and of four crossings. These, ${}_3$A and ${}_4$A(*vide* Plate XL.), are irreducible and fundamental. ${}_3$A is a 3-zoned monarchaxine, whose principal poles are triangles not plane, which have three common summits and no common edge.

The unsolid ${}_4$B is formed on ${}_3$A by art. 29, and has a symmetry of like description. The secondary 2-zoned poles on either are alternately flaps and crossings, being heteroid poles in ${}_3$A and janal in ${}_4$B.

31. *Subsolid and Unsolids of Five Crossings.*—The subsolid must be built on ${}_3$A. The only points that can be here joined by a flap, are either on one flap of ${}_3$A or on two. We cannot obtain a subsolid by joining the former pair, because the constructed knot would be an unsolid having a concurrence of two (art 13). We join the latter pair, and it matters not whether we draw our flap in the upper or in the lower of the two triangles whose summits are the same three crossings, and whose edges are different halves of the three flaps of ${}_3$A. Drawing the flap 54, the two flaps of ${}_3$A connected by it become triangles, and ${}_5$A is constructed, a 2-zoned monarchaxine heteroid, whose zoned poles are a tessarace and an opposite tetragon. This is the only subsolid of five crossings.

The unsolid ${}_5$B is by (29) formed on ${}_4$A, and ${}_5$C is made on ${}_3$A.

32. *Knots of Six Crossings.*—The subsolids ${}_6$A, &c., must be formed on ${}_4$A and ${}_4$B. This ${}_4$A has a janal 2-zoned axis through the centres of the flaps, and two like 2-ple janal zoneless axes through two pairs of opposite mid-edges. It has only one mesh, the monozone triangle 342, and the only pair of points that can be joined are $5a$ and 56.



Drawing $5a$, or rather conceiving it drawn, we write to determine the leading flap,

$(5a)=43,43$; $(12)=43,43$; $(5a)>(12)$?

This is read thus—the flap on $5a$ has for collaterals 3 and 4, and for coverticals 3 and 4; so has the flap on 12: which leads?

Next, conceiving 56 drawn, we write,

$$(56)=43,44;\ (12)=44,43;\ (43)=43,44.$$

Here by art. 19 (12) appears to be leader, until we observe that it is fixed by art. 22, and cannot be a competitor.

We therefore write more correctly,

$$(56)=43,44>(43)=43,44\ ?\ (12)\text{ is fixed};$$

which inquires, Does (56), which is 43,44, lead (43), which is also 43,44? We consider this second as well as the preceding note of interrogation a presumption of symmetry (art. 21).

Drawing the flap ($5a$) we obtain ${}_6$A, and the flap (56) gives us ${}_6$B, on both of which the leading flap so drawn is marked 56. Observe that in our figured subsolids of n crossings, the leading flap is always marked $n(n-1)$. Our presumptions of symmetry are verified in the two results ${}_6$A and ${}_6$B.

The polar edges of the heteroid zoneless axis of ${}_6$A are evident in the figure. The two-zoned axis of ${}_6$B has for faces a flap and an opposite 4-gon. The other two flaps of ${}_6$B are like epizonals.

It was possible to connect by a flap the two edges of the flap 43 in ${}_4$A. But this could have completed an unsolid having a linear section through 3 and 4; and completed it wrong, because no unsolid is ever made by so adding a flap.

33. We next take the unsolid ${}_4$B, considering whether or no a flap can be drawn on it to make it a subsolid of six crossings. Readily we perceive that by joining two opposite flaps we can both spoil the concurrence and block the linear section. This gives us ${}_6$C, which has all the symmetry of the wedge which it becomes when an edge is removed from every flap. The three, ${}_6$A ${}_6$B and ${}_6$C, are all the subsolids of six crossings.

34. We seek now the unsolids of six crossings. To obtain them by least marginal charge or charges (art. 25), we have to lay 2 upon 4 and 3 upon 3.

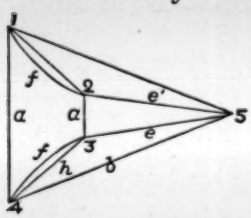
There is but one charge that can add two crossings only, ${}_4$A*ffc*, which means ${}_4$A imposed (art. 15), by the section *ffc*. Imposing this on ${}_4$A we get ${}_6$D, a zoned triaxine, whose three janal 2-zoned axes have for poles, one two tessaraces, a second two flaps, and the third two 4-gons symmetrical but not plane, which have two common summits and no common edge.

Laying next on ${}_3$A the charge ${}_3$A*ff* (art. 15), we obtain ${}_6$E, another zoned triaxine, whose janal poles are two edges, two tessaraces, and two hexagons alike and non-planar. There is in truth no least marginal subsolid in either ${}_6$D or ${}_6$E, the two halves of the knot being identical in each. But it is instruc-

tive, and involves no error, here to consider them as cases of the linear sections *ffc* and *ff*.

35. We have constructed all the knots of six crossings that are without a concurrence, viz., ${}_6$A, ${}_6$B, ${}_6$C, ${}_6$D, ${}_6$E. Those having concurrences are obtained, ${}_6$F on ${}_5$A, ${}_6$G and ${}_6$H on ${}_4$A, and ${}_6$I on ${}_3$A. These nine, ${}_6$A . . . ${}_6$I, along with the solid knot ${}_6$J, are the ten possible knots of six crossings. Four of them, as TAIT has found and drawn them, are unifilar, viz., ${}_6$A, ${}_6$E, ${}_6$F, ${}_6$G; and this is read on the figures. The number 12 on each shows that there are 12 steps in the circle of the knot, which passes twice through every crossing, once over and once under. ${}_6$B, ${}_6$D, and ${}_6$H are bifilars; ${}_6$C and ${}_6$J are trifilars.

36. *Knots of Seven Crossings.*—The subsolids ${}_7$A, &c., must be built on ${}_5$A, &c. The only lines that can be drawn on ${}_5$A here given are *ff* and *aa*, each 44; and *af*, *ae'*, *ee'* *be*, *bh*, each 34.



By *ff*, which has no rival, we get ${}_7$A; whose 2-zoned poles are the flap and the tessarace 3333,

$(aa)=44>(12)$, or $(34)=43$;
$(af)=53, 43>(12)=53, 43$?
$(bh)=43, 43>(12)=43, 43$?

For the rest, *ae'*, *be*, and *ee'*,

$(43)=53>(ae')=43$;
$(43)=44>(be)=43$ and $>(ee')=43$.

We have to draw, besides *ff*, the flaps (aa) (af) and (bh), expecting symmetry with the two last, which we soon find.

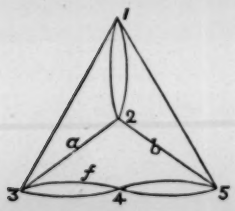
By (aa) we get ${}_7$B,

whose 2-zoned poles are this flap and a tessarace.

By (af) comes ${}_7$C, monozone;
By (bh) „ ${}_7$D,

whose zoneless 2-ple poles are a 4-gon and a 4-ace. Thus there are four subsolids, ${}_7$A, ${}_7$B, ${}_7$C, ${}_7$D, reducible by the leading flap to ${}_5$A.

37. On ${}_5$B, annexed, as we cannot allow a concurrence, we can draw only (af) and (bf),



$(af)=53>(12)=43$, and (45) is fixed (art. 22).
$(bf)=44, 43$. $(45)=44, 43$? $\big((12)=34\big)$,

for (45) is not fixed when (bf) is drawn.

We have to draw (af) and (bf) looking for symmetry in the latter.

(af) gives us $_7$E, asymmetric;
(bf) „ $_7$F, monozone.

Thus there are six subsolids, $_7$A $_7$B . . . $_7$F, of which we read on their figures that $_7$C, $_7$D, and $_7$E are unifilar.

38. To obtain the unsolids $_7$G, &c., without concurrences, we have to lay 2 upon 5, 3 upon 4, and 2 . 2 upon 3,

$_4$A*ffc* on $_5$A gives $_7$G, monozone.

This is 2 upon 5. We cannot lay the same charge on $_5$B destroying the concurrence, without completing an unsolid having two marginal charges of which we have just imposed only one; which is forbidden (art. 25).

For 3 upon 4,

$_3$A*ff* on $_4$A gives $_7$H:
$_3$A*fe* on $_4$A gives $_7$I; *vide* the figures.

Observe that we can impose $_3$A only by the sections *ff* and *fe*; for it has no edge to lose at a section *ef* or *ee*; and if we attempt to lay it on a flap *h* by *ffc*, we merely turn *h* into a concurrence of two, which is not permitted as a result of any charging operation.

In $_7$H and $_7$I the 2-zoned and the zoneless 2-ple axes of $_4$A, after being loaded symmetrically by $_3$A, retain their repeating polarity, but from being janal have become heteroid, not janal.

For 2 . 2 upon 3, we lay on $_3$A the two charges $_4$A^2*ffc*, which stands for twice $_4$A*ffc*. The result is $_7$J, in which one flap is zoned polar, and two are epizonal. Thus there are four unsolids, $_7$G, $_7$H, $_7$I, $_7$J, without concurrence.

39. For unsolids, $_7$K, &c., having concurrences, we obtain on $_6$A, $_7$K; on $_6$B, $_7$L and $_7$M; on $_6$C, $_7$N; on $_6$D, $_7$P; on $_6$E, $_7$Q; on $_5$A $_7$R and $_7$S; on $_4$A, $_7$T and $_7$U; on $_3$A, $_7$V; eleven of them.

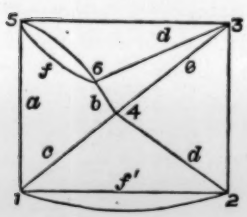
Thus we have 21 knots of seven crossings, of which 6 are subsolids and 15 are unsolids. Their symmetry and circles are to be read on their figures.

Twelve of them, $_7$C, $_7$D, $_7$E, $_7$G, $_7$H, $_7$I, $_7$L, $_7$P, $_7$S, $_7$T, $_7$U, $_7$V, are unifilar, of which all but $_7$I have been found and figured by TAIT. See Plate XV., *Trans. R.S.E.*, 1876–77, for his eleven figured unifilars, and his reduction of them to eight.

40. The meaning of the symbols *ffc*, *ff*, and *fe* is clear from the figures $_7$G, $_7$H, $_7$I. In reduction of $_7$G, after making the linear section, two flaps have to be restored. Also after section of the two parallels in $_7$H, the cut portions have to be united to make two flaps on the severed knots; and after section in $_7$I they have to be united to restore the flap on the charge $_3$A and the edge on $_4$A.

We shall see an example of the section *ef* in $_9$D*g*, and of *ee* in $_8$A*k* and $_9$D*i*; *vide* the figures.

41. *Construction of Knots of Eight Crossings.*—For the subsolids ${}_8$A, &c., we have to draw leading flaps on ${}_6$A, &c. In ${}_6$A, which is figured here, the 2-ple zoneless heteroid axis passes through a and e. The only faces are 5641, 634, and 563, and there is one flap which is asymmetric, having different edges marked f and f'. The only different lines that can be drawn are



fa, fb, ca, cb, each 35;
fc and ab, each 44; and
$f'd, f'c, be, bd, de, dc$, each 34.

The two d's are the same point repeated in the repeated triangles 563 and 124.

$(fa) = 53, 53 > (12) = 53, 53$?
$(fb) = \quad 53 > (12) = 43$;
$(ca) = 53, 54 > (56) = 53, 53$; (12) is fixed (art. 22);
$(cb) = 53, 44 > (56) = 53, 44$?
$(fc) = 44, 43 > (12) = 44, 43$?
$(f'd) = 43, 43 > (12) = 43, 43$?
$(bd) = 43, 54 > (12) = 43, 53$; (56) is fixed (art. 23).

For the rest,

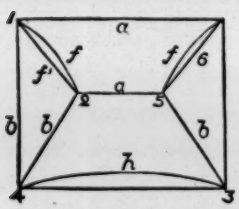
(12) leads (ab); and (56) leads $(f'c)$ (be), (de) and (dc).

We have to draw seven flaps, expecting symmetry in four cases—

(fa) gives us ${}_8$A;	(ca) gives us ${}_8$E;
(fc) „ ${}_8$B;	(cb) „ ${}_8$F;
(fb) „ ${}_8$C;	(bd) „ ${}_8$G;
$(f'd)$ „ ${}_8$D;	

whose symmetry and circles are read on their figures, where the zoneless poles on ${}_8$A, ${}_8$B, and ${}_8$D are 55 and 33, 44 and 33, 44 and 44, and the leading flaps are marked 78.

42. We take next ${}_6$B, whose only faces are the 2-zoned polar 1256, and the monozone faces 4253 and 124. The only lines drawable are,



[The 6 should be at the base corner.]

fa, ba, hb, each 35,
ff, aa, bb, ha, each $=44$,
and $f'b, bb$, each $=43$.

Here (43) is fixed for every flap that we can draw, except (ff) and (bb), each $=44$.

$(ba) = 53, 54 > (56) = 53, 54$? (12) and (43) are fixed (arts. 22, 23).
$(hb) = \quad 53 > (12) = 44$ and $> (56) = 43$.
$(bb) = 44, 44 >$ (12) or (56) or (43)? each $= 44, 44$.
$(ff) = 44, 33 > (43) = 44, 33$?
$(aa) = 44 \quad > (12) = 43$ and $> (56) = 43$.

For the rest,

(56) leads (fa) and $(f'b)$ from the flap (12),

and (12) leads $(bb)=43$.

We have to draw five flaps, presuming symmetry with (ba), (bb), and (ff).

(ff) gives us ${}_8\mathrm{H}$,

whose three 2-zoned janal axes terminate in the centres of the zoned polar flaps and of two pairs of edges 44, 44; and 33, 33.

(hb) gives us ${}_8\mathrm{I}$, asymmetric,

(bb) gives us ${}_8\mathrm{J}$,

whose two janal zoned poles are 4-gons, the four like janal zoneless 2-ple poles being edges 44. We often mean by pole the polar face summit or edge in which an axis ends.

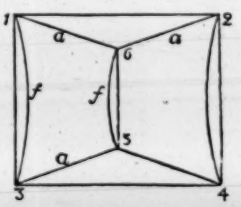
(aa) gives us ${}_8\mathrm{K}$,

having two different zoned polar flaps:

(ba) gives us ${}_8\mathrm{L}$,

whose zoneless poles are 44 and 55.

43. Our next base is ${}_6\mathrm{C}$, which has one flap, one triangle, and one 4-gon. The only different lines that can be drawn are ff and aa, each 44, and fa and aa, each 43. The two f's are alike.



$(ff)=44, 33>(23)=43, 33$?

$(aa)=44$ $>(32)$ or (56) or (14) ? each $=44$;

not $(fa)=53$ $>(14)=54$;

nor $(aa)=43$ $>(14)=54$.

We have two flaps only to draw.

(ff) gives ${}_8\mathrm{M}$,

whose zoned poles are the flaps, the four like zoneless 2-ple poles being tessaraces.

$(aa)=44$ gives ${}_8\mathrm{N}$,

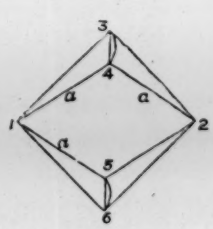
whose eight janal secondary 2-zoned poles are alternately flaps and 4-gons.

44. We have no more subsolids of six crossings. Of the unsolids, we find only four, ${}_6\mathrm{D}$, ${}_6\mathrm{E}$, ${}_6\mathrm{F}$, and ${}_6\mathrm{G}$, on which a flap can be drawn to block linear section.

We have on ${}_6\mathrm{D}$, in $1aa$, and $14aa$,

$(aa)=53>(34)$ and $>(56)$, each $=43$.

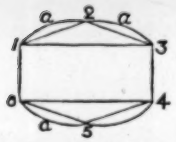
$(aa)=44>(34)$ or (56) each $=43$.



By $(aa)=53$ we get ${}_8\mathrm{P}$.

By $(aa)=44$ we get ${}_8\mathrm{Q}$, *vide* the figures.

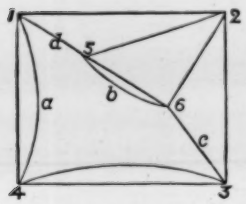
We have on ${}_6$E,



$(aa)=64>(23)$ or $(45)=63$.
$(aa)=55>(12)$ or $(45)=53$.

By $(aa)=64$ we get ${}_8$R, and
by $(aa)=55$ we get ${}_8$S.

Upon ${}_6$F we see that (ab), (ad), (ac), are the only flaps that can block linear section and exclude concurrence,

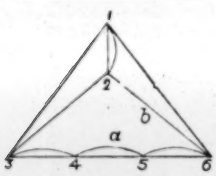


$(ab)=54, 33>(43)=54, 33$?
$(ac)=54 \quad >(43)=44$,
not $(ad)=63 \quad >(43)=64$.

Drawing the flaps (ab) and (ac) we get ${}_8$T and ${}_8$U.

Upon ${}_6$G only (ab) can exclude concurrence. Here (34) is fixed (art. 22).

$(ab)=54>(56)=54$? $(12)=34$.



Drawing (ab) we obtain ${}_8$V symmetric as we expected, having three different flaps, one zonal, one epizonal, and one asymmetric.

One more subsolid, ${}_8$W, is built on ${}_6$J, which has only one edge and one angle.

We have constructed twenty-two subsolids of eight crossings, ${}_8$A ... ${}_8$W, whose symmetry and circles are seen on their figures. Seven of them are unifilar.

In naming these knots I use an alphabet of 25 letters, omitting the letter O. Thus,

A, B, ... z; Aa, Ab, ... Az; Ba, Bb, ... Bz;

are each a set of 25.

45. For the unsolids ${}_8$X, &c., of eight crossings which have no concurrence, we have to lay 2 upon 6, 3 upon 5, 4 and 2·2 upon 4.

For 2 upon 6 we can impose ${}_4$A*ffc* on ${}_6$A once, on ${}_6$B twice, on ${}_6$C once, on ${}_6$E once, and on ${}_6$F once, but on no other of six crossings, without violating the rules in arts. 25, 28.

${}_4$A*ffc* on ${}_6$A gives ${}_8$X;
" ${}_6$B " ${}_8$Y and ${}_8$Z;
" ${}_6$C " ${}_8$Aa;
" ${}_6$E " ${}_8$Ab;
" ${}_6$F " ${}_8$Ac;

whose descriptions are read on their figures. The monozone ${}_8$Ab has four different flaps, one epizonal upon the marginal charge, and three zonals, in the zonal plane.

For 3 upon 5,

$_3$A*ff* on $_5$A gives $_8$A*d*;
$_3$A*fe* on $_5$A gives $_8$A*f* and $_8$A*c*;
$_3$A*fe* on $_5$B attempted gives $_8$Z

erroneously, or leaves a concurrence. $_5$A*ffe* on $_5$A gives $_8$A*g*, by arts. 16, 17, and $_8$A*h*, art. 27.

For 4 upon 4,

$_4$A*ff* on $_4$A gives $_8$A*i*;
$_4$A*fe* on $_4$A „ $_8$A*j*;
$_4$A*ee* on $_4$A „ $_8$A*k* and $_8$A*l*.

The janal zoned poles on $_8$A*i* are two flaps, two edges of the 4-gon, and two opposite not plane 6-gons. The two poles of $_8$A*j* are a flap and an edge 33: on $_8$A*k* the janal zoneless poles are edges 33: on $_8$A*l* are two pairs (66) and (33) of janal zoneless 2-ple poles; and a third pair are two 6-gons not plane.

There are two constructions by the charge $_4$A*ee*, because neither ϵ nor ϵ' (art. 27) is zoned polar.

For 2·2 on 4 (art. 38),

$_4$A^2*ffe* on $_4$A gives $_8$A*m*,

which has all the symmetry of $_4$A; the four 2-ple zoneless janal poles are where they were, and the zoned janal poles are the two flaps of the imposed charges.

Finally,

$_4$A^2*ffe* on $_4$B gives $_8$A*n*,

having a janal zoned pole in each flap, and another pair in opposite non-plane 6-gons.

$_8$A*p* is the only solid knot of eight crossings, a 4-zoned monarchaxine homozone, whose eight identical janal 2-ple zoneless poles bisect eight polar edges 33. Thus we have constructed seventeen unsolids without concurrence, $_8$X $_8$Y ... $_8$A*n*, of which nine are unifilar.

46. We complete our list of unsolids by art. 29—

$_7$A gives $_8$A*q*;	$_7$J gives $_8$B*g*, $_8$B*h*;
$_7$B „ $_8$A*r*, $_8$A*s*;	$_6$A „ $_8$B*i*, $_8$B*j*;
$_7$C „ $_8$A*t*;	$_6$B „ $_8$B*k*, $_8$B*l*, $_8$B*m*, $_8$B*n*;
$_7$D „ $_8$A*u*;	$_6$C „ $_8$B*p*, $_8$B*q*;
$_7$E „ $_8$A*v*, $_8$A*w*, $_8$A*x*;	$_6$D „ $_8$B*r*, $_8$B*s*;
$_7$F „ $_8$A*y*, $_8$A*z*;	$_6$E „ $_8$B*t*, $_8$B*u*;
$_7$G „ $_8$B*a*, $_8$B*b*;	$_5$A „ $_8$B*v*, $_8$B*w*;
$_7$H „ $_8$B*c*, $_8$B*d*;	$_4$A „ $_8$B*x*, $_8$B*y*, $_8$B*z*;
$_7$I „ $_8$B*e*, $_8$B*f*;	$_3$A „ $_8$C*a*.

Of these 36 we have figured only half, the 18 of them which are unifil

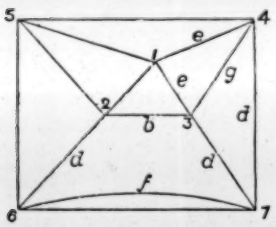
as in the unifilars appears to lie mainly the interest of these knots. The 18 plurifils (if ever they deserve a name) can easily be drawn by the student with the aid of the above list; and they must be figured by him who constructs the 10-fold knots, for on many of them flaps can be drawn to make subsolids of ten crossings.

We have found of eight crossings,

1 solid knot, unifilar,
22 subsolids, ${}_8\mathrm{A} \ldots {}_8\mathrm{W}$,
17 unsolids without concurrences
36 unsolids with concurrences;

in all 76 8-fold knots, of which 35 are unifilar.

47. *Construction of Knots of Nine Crossings.*—The subsolids ${}_9$A, &c., are to be formed by drawing leading flaps on ${}_7$A, &c.



The only lines that differ on ${}_7$A here figured are,

fb and *dd*, each=44;
df, *dd*, *db*, *dg*, *ge*, *ee*, *eb*, each=34:

2376, 347, 123, and 134 are the only faces. The *d*'s are alike, all on the same asymmetric edge 34, which has two different sides.

(*fb*)=44, (*fd*)=43, and (*dd*)=43, have no competitors; for this (*dd*) fixes (67) (art. 23),

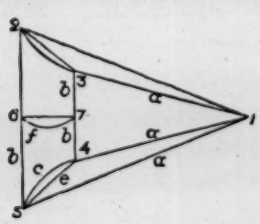
$$(dd)=44,44>(67)=44,44\ ?$$

All the lines =34, except *fd* and *dd*, are led by (67). We have four flaps to draw, expecting symmetry with (*dd*)=44.

By (*dd*)=44 we get ${}_9$A; by (*dd*)=43 we get ${}_9$D;
„ (*fb*)=44 „ ${}_9$B; „ (*fd*) „ ${}_9$C.

The symmetry and circles of these four knots are read on their figures.

48. We consider next ${}_7$B, here drawn. This has the faces 1473, 6745, and 541, with one zoned polar and one epizonal flap. The different lines that can be drawn are,



ab, *aa*, *fb*, *bb*, and *cb*, each=53,
ab, *fc*, and *bb*, each=44,
aa and *ae*, each=43.

In *b*7*b* (*bb*) =53, 55>(23) or (54) each 53 54; (67) is fixed (art. 23)
(*aa*)=53 >(23, 67 or 54) each=44;
(*fc*) =44 >(23)=43;
In 67*bb* (*bb*) =44, 55>(67)=44, 55? (45)=(23)=43.

For the rest,

(54) leads (fb), $(aa)=44$ and $(ab)=44$,
(67) leads $(ab)=35$, (ea) and (cb).

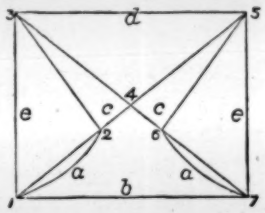
We have to draw $(bb)=53$, (aa), (fc) and $(bb)=44$, expecting symmetry with the last,

$(bb)=53$ gives ${}_9\mathrm{E}$; $(bb)=44$ gives ${}_9\mathrm{G}$;
(fc) „ ${}_9\mathrm{F}$; (aa) „ ${}_9\mathrm{H}$;

whose symmetry and circles are on their figures.

49. ${}_7\mathrm{C}$ annexed has monozone faces 1357, 12467, 354, and asymmetric faces 456, 567, and the flap.

The different lines on it are,



ab, ac, cc, each 36;
aa, ac, bc, each 45;
bd, ee, each 44;
ed, eb, each 35;

besides lines 34 that can be drawn in triangles.

(aa) has no rival:
in $1ab$, $(ab)=63, 53>(67)=63, 53$?
in $2ac$, $(ac)=63, 43>(67)=63, 43$?
in $24ca$ $(ac)=\quad 54>(67)=53$;
in $12cb$ $(bc)=\quad 54>(67)=53$ or $(12)=43$;
$(cc)=63, 44>(12)$ or (67) each $=63, 44$?

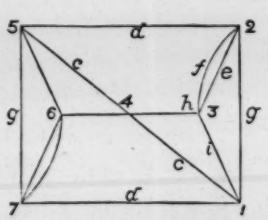
For the rest, (12) or (67) leads them all, as well as all flaps on lines 34.

We have to draw six flaps, looking for symmetry with three,

(aa) gives us ${}_9\mathrm{I}$; (ab) gives us ${}_9\mathrm{J}$;
In $2ac$ (ac) „ ${}_9\mathrm{K}$; (ac) „ ${}_9\mathrm{L}$ in $24ca$.
in $21bc$ (bc) „ ${}_9\mathrm{M}$; (cc) „ ${}_9\mathrm{N}$.

The symmetry and circles of these are on the figures.

50. Next comes ${}_7\mathrm{D}$ here drawn. The polar 4-gon is 5217, and the asymmetric faces are 5234, 123, 143. The only different lines to be drawn are,



fd, fh, ch, cd, dg_1 in $1dg$, and dg_7 in $7dg$, all 53;
fc, dd, dh, gg, all 44;
eg, ei, gi, hc, hi, ci, all 43; 16 lines.

$(fd)=53>(67)=43$;
$(fh)=53>(67)=43$;
$(cd)=53, 54>(32)=53, 53$; $(67)=43$;
$(dg_1)=53, 54>(67)=53, 53$, or $(32)=44$;
$(dg_7)=53\quad>(32)=43$; and (67) is fixed (art. 23);

in $c4h$, $(ch) = 53, 44 > (32) = 53, 44$? (67) is 43;
$(fc) = 44 > (76) = 43$;
$(dh) = 44 > (76 \text{ or } 32) = 43$;
$(gg) = 44, 44 > (76 \text{ or } 32) = 44, 43$
$(eg) = 43, 53 > (76) = 43, 53$?
$(ei) = 43, 43 > (76) = 43, 43$?
$(hi) = 43, 54 > 43, 43$; (23) is fixed (art. 23).

For the rest,

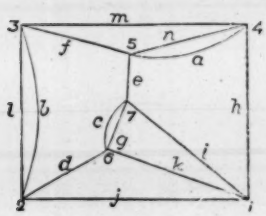
(32) leads dd, gi, ci, and $hc = 43$.

We have twelve flaps to draw, expecting with three at least symmetry:

(fd)	gives ${}_9\mathrm{P}$;	(fc)	gives ${}_9\mathrm{V}$;
(fh)	„ ${}_9\mathrm{Q}$;	(dh)	„ ${}_9\mathrm{W}$;
(cd)	„ ${}_9\mathrm{R}$;	(gg)	„ ${}_9\mathrm{X}$;
(gd_1)	„ ${}_9\mathrm{S}$;	(eg)	„ ${}_9\mathrm{Y}$;
(ch)	„ ${}_9\mathrm{T}$;	(ei)	„ ${}_9\mathrm{Z}$;
(dg_7)	„ ${}_9\mathrm{U}$;	(hi)	„ ${}_9\mathrm{A}a$.

The poles of ${}_9\mathrm{X}$ are a tessarace and the leading flap. The symmetry and circles of all are read on figures.

51. Our next subsolid base is E_7 appended, on which no two edges are alike. Thirty-one different flap-lines can be drawn on it, namely,



bd, bf, cd, cc, fe, all 63;
bc, be, cf, fd, de, all 54;
ae, ah, lm, lj, hm, hj, hi, ie, all 53;
ai, hl, eh, jm, all 44;
fm, nf, nm, gk, gi, ik, jd, jk, kd, all 43;

the lines *lm*, &c., in the base being supposed dotted.

$(bf) = 63, 43 > (67) = 63, 43$? $54 = 44$;
$(cd) = 63 > (54) = 43$;
$(ce) = 63 > (54) = 53$;
$(be) = 54 > (54) = 43$;
$(be) = 54 > (54 \text{ or } 67) = 53$;
$(cf) = 54, 43 > (23) = 54, 43$? $(54) = 44$;
$(fd) = 54 > (23 \text{ or } 54) = 44$ and $> (67) = 53$;
$(de) = 54 > (54) = 53$, or $(67) = 43$; (23) is fixed;
$(lm) = 53, 43 > (67) = 53, 43$? $(67) = 44$;
$(dk) = 43, 64 > (54) = 43, 64$? (67) and (23) are fixed
$(ie) = 53, 64 > (54) = 53, 64$? „ „

For the rest,

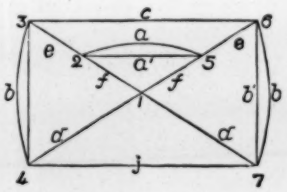
(23) leads *nf, ah, ae, ai, mh, cf, mj, mn*;
(67) „ *hl, he, hi, bd, lj, jd, mf*;
(54) „ *gi, gk, ik, jk, jh*.

We have eleven flaps to draw, with five queries about symmetry, which speedily reveals itself,

(bf)	gives ${}_9\mathrm{A}b$;	(fd)	gives ${}_9\mathrm{A}h$;
(cd)	„ ${}_9\mathrm{A}c$;	(de)	„ ${}_9\mathrm{A}i$;
(ce)	„ ${}_9\mathrm{A}d$;	(lm)	„ ${}_9\mathrm{A}j$;
(bc)	„ ${}_9\mathrm{A}e$;	(dk)	„ ${}_9\mathrm{A}k$;
(be)	„ ${}_9\mathrm{A}f$;	(ie)	„ ${}_9\mathrm{A}l$.
(cf)	„ ${}_9\mathrm{A}g$;		

The symmetry and circles of all are written on their figures. The poles of ${}_9\mathrm{A}j$ are the tessarace common to the two 5-gons, and the flap which connects them: those of ${}_9\mathrm{A}k$ are a 6-gon and a 4-ace.

52. The sixth and last subsolid is ${}_7\mathrm{F}$, which has only one asymmetric face (1567), and one asymmetric flap (67). The flap (25) is epizonal. Eighteen different flap-lines can be drawn:



ae, b'd, b'e, bj, bc, ef, ee, fd, all 53 (*bj* and *bc* dotted below);
ac, bb, b'f, ce, cd, cj, all 44;
ff, a'f, dd, dj, all 43.

$(bb)=44>(25)=43$;
$(b'd)$ in $b'd7=53>(25)=43$ and $>(34)=44$.

For the rest,

(25) leads *b'e, b'f, cj, cd*;
(34) leads *ae, ee, ec, ac, a'f, dd,* and *dj* in $7dj$;
(67) leads *fd, bc* in $3bc$, *ff, fe,* and *bj* in $4bj$.

We have two flaps to draw,

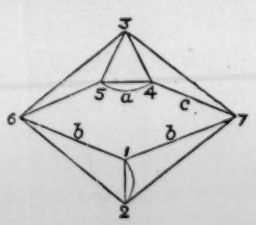
(bb) giving ${}_9\mathrm{A}m$ and $(b'd)$, giving ${}_9\mathrm{A}n$,

whose circles and symmetry are read on the figures.

53. We betake ourselves next to the unsolids of seven crossings, which, by a leading flap, can become subsolids. These are

${}_7\mathrm{G}$, ${}_7\mathrm{H}$, ${}_7\mathrm{I}$, ${}_7\mathrm{J}$, ${}_7\mathrm{K}$, ${}_7\mathrm{L}$, ${}_7\mathrm{M}$, ${}_7\mathrm{N}$, ${}_7\mathrm{Q}$, ${}_7\mathrm{R}$, ${}_7\mathrm{S}$

On ${}_7\mathrm{G}$ annexed can be drawn to block the linear section only three lines, which are



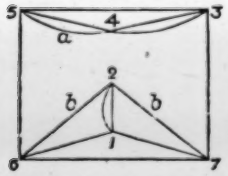
$(ab)=54>(12)=43$;
in $cb7$, $(cb)=63,44>(54)=63,43$ and $>(12)=43$;
in $cb17$, $(cb)=54>(54)=53$ and $>(12)=43$.

We draw three flaps,

(ab) giving ${}_9\mathrm{A}p$, (cb) giving ${}_9\mathrm{A}g$, and (cb) giving ${}_9\mathrm{A}r$;

whose description is seen on their figures.

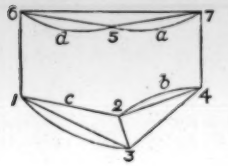
54. On $_7$H, here seen, we can draw two flaps only,



$(ab) = 64$ (in $56ba$) $> (43) = 63$ or $(21) = 43$.
$(ab) = 55$ (in $562ba$) $> (43) = 53$ or $(21) = 43$.

One (ab) gives $_9$As, the other gives $_9$At.

Four flaps can be drawn on $_7$I annexed,

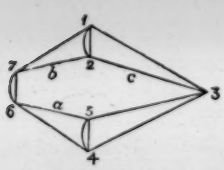


$(ab) = 64 > (56) = 63$ or $(13) = 53$;
$(db) = 55 > (57) = 53$ or $(13) = 53$;
$(ac) = 55 > (24$ or $56) = 53$ and $> (13) = 54$;
$(dc) = 64 > (57$ or $24) = 63$ and $> (13) = 54$.

Here (ab) gives $_9$Au; (ac) gives $_9$Aw;
(db) „ $_9$Av; (dc) „ $_9$Ax.

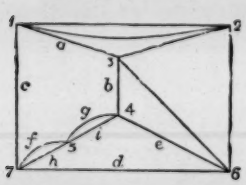
Professor TAIT does not allow $_7$H and $_7$I to be different knots, giving a reason at p. 158, *Trans. R.S.E.* 1876–7, which appears to me sufficient wherever it can be verified without twisting the tape, or breaking the law of alternate over and under. It is true that on the knot in space whose projection is $_7$H, the three crossings 543 which are found on the thread 67 between 6 and 7, can by slipping of the thread be made to appear on the thread 71; so that the order of the crossings shall be changed from 165435437 . . , the thread passing over at 15347, to 167543543 . . , the thread passing over at 17534, *i.e.*, making two consecutive overs at 7 and 5. The resultant figure in space, although it would have $_7$I for its projection, would, if I am in the right, be no knot. If I had not drawn both $_7$H and $_7$I, I should have missed some unifilar 9-fold knots, both here and in art. 63.

55. On $_7$J, annexed, can be drawn only two lines to make a subsolid,



$(ab) = 54, 44(67) = 54, 44$? $(54 = 12) = 43$.
$(ac) = 54, 44 > (12$ or $54) = 43$; (67) is fixed.
(ab) gives $_9$Ay, and (ac) gives $_9$Az.

On $_7$K, here seen, can be drawn flaps only from f, g, h, or i, so as to spoil both concurrence and linear section,



$(fa) = 54, 43 > (54) = 54, 33$; $(12) = 44$;
$(fb) = 54 > (54) = 44$; $(12) = 43$;
$(ga) = 54, 43 > (57) > 54, 43$? $(12) = 44$;
$(gc) = 54 > (57) = 44$, or $(12) = 53$.

A flap (fy) can be drawn, but the linear section 74 would remain. For the rest,

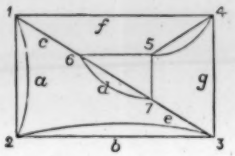
(45) leads fc, he, hd; (75) leads bg, ic, id.

Here

(fa) gives ${}_9\mathrm{B}a$; (ga) gives ${}_9\mathrm{B}c$;
(fb) „ ${}_9\mathrm{B}b$; (gc) „ ${}_9\mathrm{B}d$.

The circles and symmetry are on the figures.

56. On ${}_7\mathrm{L}$, here given, no line can be drawn to spoil the concurrence and the linear section but from a or b,

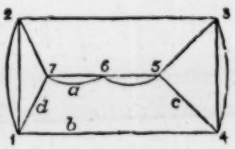


$(ae) = 54 \quad > (23) = 44$ and $> (67) = 53$; (54) is fixed (art. 22).
not $(ac) = 63 \quad > (23) = 64$;
not $(ad) = 54, 33 > (23) = 54, 43$;
not $(bg) = 53, 53 > (67) = 53, 54$;
not $(bf) = 44 \quad > (67) = 53$.

Here

(ae) gives us ${}_9\mathrm{B}e$.

On ${}_7\mathrm{M}$, here seen, the leading flap must be drawn from a.



$(ad) = 63 \quad > (12) = 44$, or $(34) = 43$;
$(ab) = 54 \quad > (12$ or $34) = 53$; (56) is fixed (art. 22).
$(ac) = 54, 43 > (56) = 54, 43$? $(34) = 44$.

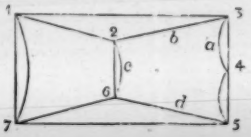
Here

(ad) gives ${}_9\mathrm{B}f$, (ab) ${}_9\mathrm{B}g$, and (ac) ${}_9\mathrm{B}h$, the latter symmetrical.

57. On ${}_7\mathrm{N}$, annexed,

$(ad) = 54 > (42, 26, 17) = 54$?

(26) leads (ab), and (45) leads (ac).



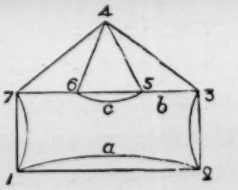
The only leader

(ad) gives us ${}_9\mathrm{B}i$, symmetric.

On ${}_7\mathrm{P}$ no flap can spoil both concurrence and linear section.

On ${}_7\mathrm{Q}$ there can be drawn only one leading flap—

$(ab) = 56$, giving ${}_9\mathrm{B}j$.

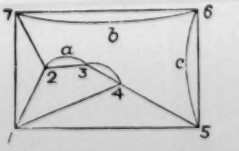


On ${}_7\mathrm{R}$, here given,

$(ac) = 55 > (32$ or $17) = 55$?
(ab) is led by (17).

Here (ac) gives us ${}_9\mathrm{B}k$, symmetric.

On ${}_7\mathrm{S}$, annexed,



$(ac) = 55 > (76$ or $34) = 54$.
$(ab) = 64 > (56$ or $34) = 64$?

Here (ac) gives ${}_9\mathrm{B}l$, and (ab) ${}_9\mathrm{B}m$, the latter symmetric.

We have constructed by their leading flaps sixty-three subsolids of nine crossings, of which thirty are unifilars, bearing on their figures the number 18.

58. We demand next the number of the unsolid 9-fold knots, and first, of those which have no concurrence.

To construct these we are to lay 2 upon 7, 3 upon 6, 4 and 2·2 upon 5, and 3·2 upon 3.

For 2 upon 7 (art. 34) imposing ${}_4\mathrm{A}ffc$, we get

On ${}_7\mathrm{A}$, ${}_9\mathrm{B}n$;
" ${}_7\mathrm{B}$, ${}_9\mathrm{B}p$ and ${}_9\mathrm{B}q$;
" ${}_7\mathrm{C}$, ${}_9\mathrm{B}r$;
" ${}_7\mathrm{D}$, ${}_9\mathrm{B}s$;
" ${}_7\mathrm{E}$, ${}_9\mathrm{B}t$, ${}_9\mathrm{B}u$, ${}_9\mathrm{B}v$;
" ${}_7\mathrm{F}$, ${}_9\mathrm{B}w$, ${}_9\mathrm{B}x$;
" ${}_7\mathrm{G}$, ${}_9\mathrm{B}y$;
" ${}_7\mathrm{H}$, ${}_9\mathrm{B}z$, ${}_9\mathrm{C}a$;

On ${}_7\mathrm{I}$, ${}_9\mathrm{C}b$, ${}_9\mathrm{C}c$;
" ${}_7\mathrm{K}$, ${}_9\mathrm{C}d$, ${}_9\mathrm{C}e$;
" ${}_7\mathrm{L}$, ${}_9\mathrm{C}f$;
" ${}_7\mathrm{M}$, ${}_9\mathrm{C}g$;
" ${}_7\mathrm{N}$, ${}_9\mathrm{C}h$;
" ${}_7\mathrm{Q}$, ${}_9\mathrm{C}i$;
" ${}_7\mathrm{R}$, ${}_9\mathrm{C}j$.

On ${}_7\mathrm{J}$ we do nothing, because we cannot cover both its least marginal charges; and nothing on ${}_7\mathrm{P}$, because we cannot both spoil the concurrence and cover the least marginal charge.

59. For 3 upon 6, the charge must be ${}_5\mathrm{A}ffc$ (art. 26) or ${}_3\mathrm{A}ff$, or ${}_3\mathrm{A}fe$,

${}_5\mathrm{A}ffc$ on ${}_6\mathrm{A}$ gives ${}_9\mathrm{C}k$ and ${}_9\mathrm{C}l$;
" ${}_6\mathrm{B}$ " ${}_9\mathrm{C}m$, ${}_9\mathrm{C}n$, ${}_9\mathrm{C}p$;
" ${}_6\mathrm{C}$ " ${}_9\mathrm{C}q$.

On ${}_6\mathrm{D}$ we cannot cover both marginals ${}_4\mathrm{A}ffc$.

On ${}_6\mathrm{E}$ we cannot cover both.

On ${}_6\mathrm{F}$, ${}_5\mathrm{A}ffc$ imposed to spoil the concurrence would be ${}_5\mathrm{A}^2ffc$ on ${}_3\mathrm{A}$ wrongly constructed by one charge ${}_5\mathrm{A}ffc$ only.

On ${}_6\mathrm{G}$ we cannot both spoil the concurrence and cover the least marginal.

On ${}_6\mathrm{H}$ it requires two charges to spoil the two concurrences.

Next, for 3 upon 6 again,

${}_3\mathrm{A}ff$ on ${}_6\mathrm{A}$ gives ${}_9\mathrm{C}r$;
${}_3\mathrm{A}fe$ on ${}_6\mathrm{A}$ " ${}_9\mathrm{C}s$, ${}_9\mathrm{C}t$, ${}_9\mathrm{C}u$, ${}_9\mathrm{C}v$, ${}_9\mathrm{C}w$;

for the e charged on ${}_6\mathrm{A}$ (art. 41) is in turn every different edge, a,b,c,d,e.

${}_3\mathrm{A}ff$ on ${}_6\mathrm{B}$ gives ${}_9\mathrm{C}x$, ${}_9\mathrm{C}y$;
${}_3\mathrm{A}fe$ on ${}_6\mathrm{B}$ " ${}_9\mathrm{C}z$, ${}_9\mathrm{D}a$;
${}_3\mathrm{A}ff$ on ${}_6\mathrm{C}$ " ${}_9\mathrm{D}b$;
${}_3\mathrm{A}fe$ on ${}_6\mathrm{C}$ " ${}_9\mathrm{D}c$;
${}_3\mathrm{A}ff$ on ${}_6\mathrm{F}$ " ${}_9\mathrm{D}d$;
${}_3\mathrm{A}fe$ on ${}_6\mathrm{J}$ " ${}_9\mathrm{D}e$.

60. We have next to lay 4 and 2·2 upon 5,

$_4$A*ff* on $_5$A gives $_9$D*f*;
$_4$A*ef* on $_5$A „ $_9$D*g*;
$_4$A*fe* on $_5$A „ $_9$D*h*;
$_4$A*ee* on $_5$A „ $_9$D*i*.
$_4$A^2*ffe* on $_5$A gives $_9$D*j* (art. 38).
$_4$A^2*ffe* on $_5$B „ $_9$D*k*.

$_5$B was made (art. 31) by adding a concurrence to $_4$A; but it is also $_4$A*ffe* on $_3$A, though improperly made (art. 38); and as we have two charges to impose, we can both spoil the concurrence and cover the least marginal of $_5$B, thus making $_9$D*k*.

61. Finally, we have to lay 2·3 and 3·2 upon 3,

$_5$A^2*ffe* on $_3$A gives $_9$D*l* and $_9$D*m*.
$_3$A^2*ff* on $_3$A gives $_9$D*n*. These lay 2·3 on 3.
$_4$A^3*ffe* on $_3$A gives $_9$D*p*. This lays 3·2 on 3.

In $_9$D*l*, $_9$D*m*, and $_9$D*n* the symmetry is maintained about one of the 2-zoned axes of $_3$A, though not a 2-zoned symmetry.

We have constructed 115 9-fold knots without concurrences, of which 63 are subsolids, and 52 are unsolids without concurrences. Among the 63 are 30 unifilars, and among the 52 are 25, making 55 unifilars without concurrences.

62. There remain only the 9-fold unsolids which have concurrences. The number of ways in which a knot K′ of n–c crossings can be made by adding c concurrences of flaps into K of n crossings is easily seen when the symmetry of K′ is given, K′ having no concurrence—

$_8$A gives $_9$D*q*;
$_8$B „ $_9$D*r*;
$_8$C „ $_9$D*s*, $_9$D*t*;
$_8$D „ $_9$D*u*;
$_8$E „ $_9$D*v*, $_9$D*w*, $_9$D*x*;
$_8$F „ $_9$D*y*, $_9$D*z*;
$_8$G „ $_9$E*a*, $_9$E*b*, $_9$E*c*;
$_8$H „ $_9$E*d*;
$_8$I „ $_9$E*e*, $_9$E*f*, $_9$E*g*;
$_8$J „ $_9$E*h*;
$_8$K „ $_9$E*i*, $_9$E*j*, $_9$E*k*;
$_8$L „ $_9$E*l*, $_9$E*m*;
$_8$M „ $_9$E*n*;
$_8$N „ $_9$E*p*;
$_8$P „ $_9$E*q*, $_9$E*r*;
$_8$Q „ $_9$E*s*, $_9$E*t*;
$_8$R „ $_9$E*u*, $_9$E*v*;
$_8$S „ $_9$E*w*, $_9$E*x*;
$_8$T „ $_9$E*y*;
$_8$U „ $_9$E*z*, $_9$F*a*, $_9$F*b*;
$_8$V gives $_9$F*c*, $_9$F*d*, $_9$F*e*;
$_8$W „ $_9$F*f*;
$_8$X „ $_9$F*g*, $_9$F*h*;
$_8$Y „ $_9$F*i*, $_9$F*j*, $_9$F*k*;
$_8$Z „ $_9$F*l*, $_9$F*m*;
$_8$A*a* „ $_9$F*n*, $_9$F*p*;
$_8$A*b* „ $_9$F*q*, $_9$F*r*, $_9$F*s*;
$_8$A*c* „ $_9$F*t*, $_9$F*u*, $_9$F*v*;
$_8$A*d* „ $_9$F*w*, $_9$F*x*;
$_8$A*e* „ $_9$F*y*, $_9$F*z*;
$_8$A*f* „ $_9$G*a*, $_9$G*b*, $_9$G*c*;
$_8$A*g* „ $_9$G*d*;
$_8$A*h* „ $_9$G*e*;
$_8$A*i* „ $_9$G*f*;
$_8$A*j* „ $_9$G*g*, $_9$G*h*;
$_8$A*k* „ $_9$G*i*;
$_8$A*l* „ $_9$G*j*;
$_8$A*m* „ $_9$G*k*;
$_8$A*n* „ $_9$G*l*, $_9$G*m*.

63. We have next to add two concurrences of flaps to all of ${}_7$A, &c., on which is no concurrence—

${}_7$A gives ${}_9$Gn;
${}_7$B „ ${}_9$Gp, ${}_9$Gq, ${}_9$Gr, ${}_9$Gs;
${}_7$C „ ${}_9$Gt, ${}_9$Gu;
${}_7$D „ ${}_9$Gv, ${}_9$Gw;
${}_7$E „ ${}_9$Gx, ${}_9$Gy, ${}_9$Gz, ${}_9$Ha, ${}_9$Hb, ${}_9$Hc;
${}_7$F „ ${}_9$Hd, ${}_9$He, ${}_9$Hf, ${}_9$Hg;
${}_7$G „ ${}_9$Hh, ${}_9$Hi, ${}_9$Hj;
${}_7$H „ ${}_9$Hk, ${}_9$Hl, ${}_9$Hm;
${}_7$I „ ${}_9$Hn, ${}_9$Hp, ${}_9$Hq, ${}_9$Hr;
${}_7$J „ ${}_9$Hs, ${}_9$Ht, ${}_9$Hu, ${}_9$Hv.

The number of results in any of the above cases of this article is that of the different flaps which can be made a concurrence of three plus the number of different pairs of flaps that can be made each a concurrence of two.

64. We have next to place three concurrences of flaps on ${}_6$A, &c., four on ${}_5$A, five on ${}_4$A, and six on ${}_3$A—

${}_6$A gives ${}_9$Hw, ${}_9$Hx;
${}_6$B „ ${}_9$Hy, ${}_9$Hz, ${}_9$Ia, ${}_9$Ib, ${}_9$Ic, ${}_9$Id;
${}_6$C „ ${}_9$Ie, ${}_9$If, ${}_9$Ig;
${}_6$D „ ${}_9$Ih, ${}_9$Ii;
${}_6$E „ ${}_9$Ij, ${}_9$Ik.

${}_5$A gives ${}_9$Il, ${}_9$Im, ${}_9$In;
${}_4$A „ ${}_9$Ip, ${}_9$Iq, ${}_9$Ir;
${}_3$A „ ${}_9$Is.

Finally, there is one solid knot, ${}_9$It.

The number of 9-fold knots that have concurrences is 128, of which we have figured only the 70 of them which are unifilars. The rest will have to be drawn if the census of unifilars is carried to higher values. This can easily be done.

We have found 244 knots of nine crossings, viz. :—

1 solid knot,
63 subsolids,
52 unsolids without concurrences,
128 unsolids with concurrences.

Of these 244—

30+25+70+1=126 are unifilar.

I think that no difficulty will present itself in the construction of higher n-fold knots, which has not been met in the preceding pages.

Here follow the abbreviations used in the descriptions of symmetry:—

Monch. for Monarchaxine.
Triax. or *Tri.* for Triaxine.
Triarch. for Triarchaxine.
Zo. for Zoned.
Az. for Azonal, or Zoneless.
Mox. for Monaxine.
Moz. for Monozone.
Hom. for Homozone.
Het. for Heteroid, not janal.
2*p.* for 2-ple, repetition about an axis.

POSTSCRIPT, SEPTEMBER 1, 1884.

65. As it is a brief matter, it may be worth the while to show how all solid knots can be constructed without omission or repetition.

Solid Knots, Prime and Non-prime.—A solid knot Q of n crossings is prime or non-prime according as it has or has not a crossing or summit A3B3, A and B being any meshes.

Lowest Triangle of a Solid Knot Q.—It is easily proved that no solid knot has fewer than eight triangles. The triangle L of Q is ABC, DEF, where ABC are the three covertical faces and DEF the collaterals of L, the lesser being written before the greater in both triplets.

If L′ be another triangle of Q, the lower of LL′ has the least A, whatever be the other five faces. If A=A′, the lower has the least B. If also B=B′, the lower has the least C. If ABC and A′B′C′ are alike, the lower has the least D, and so on.

If the six faces are alike in both, it is wisest, and almost sure to be right in construction, to presume that L and L′ are identical, or one the reflected image of the other, by the symmetry of Q, which is soon decided. If they are not thus proved alike, an examination of the collaterals of ABCDEF cannot fail to determine the lower triangle. The one whose A, or, if required, whose B, &c., has the lowest collaterals is the lower.

66. *Reduction of a Solid Knot* Q.—The simple rule is, efface the edges of the lowest triangle L of Q, or of a lowest when Q has a symmetry.

Such reduction of a prime solid knot Q of n crossings gives us a subsolid or an unsolid knot P of $n-3$ crossings, which has one, two, or three flaps, according as the effaced L had one, two, or three covertical triangles: and L must have one, or, by our first definition (65), it cannot be lowest on Q.

Such reduction of a non-prime Q gives either a non-prime P′ or a prime solid knot P of $n-3$ crossings; but I am not certain that this can ever be P′.

67. *Construction of Solid Knots* Q *of* n *Crossings.*—The rule is the converse of the preceding. Add to the subject P of $n-3$ crossings, whether P be solid, subsolid, or unsolid, a lowest triangle of the result Q, occupying three mid-edges of a mesh of P. I am not certain that when P is non-prime such addition can ever be made.

In order that Q may be solid, P must have fewer than four flaps, which, if more than one, must be collaterals of one mesh. If P has only one flap, it is collateral with two meshes, alike or different. Such a P must not be unsolid.

It may be that several different lowest triangles of Q may be drawn upon P, giving as many different Q, or that no lowest of Q can be drawn on P. In this case P is no base, and in construction is useless. No knot Q is reducible to it by deletion of a lowest triangle of Q. Examples are given below.

68. We proceed to construct on our figured knots P every possible solid knot Q.

Our only knots which have fewer than four flaps, all of which stand about one mesh, are ${}_3$A; ${}_5$A; ${}_6$F, ${}_6$J; ${}_7$A, ${}_7$C; ${}_8$R, ${}_8$T, ${}_8$W, ${}_8$A*d*, ${}_8$A*g*, ${}_8$A*p*, ${}_8$A*q*, ${}_8$A*t*; ${}_9$A, ${}_9$B, ${}_9$C, ${}_9$I, ${}_9$J, ${}_9$K, ${}_9$L, ${}_9$N, ${}_9$B*m*, ${}_9$B*n*, ${}_9$D*e*, ${}_9$D*l*, ${}_9$E*y*, ${}_9$F*f*, ${}_9$G*d*, ${}_9$I*t*; thirty of them, of which ${}_8$A*q*, ${}_9$E*y*, ${}_9$F*f* are not figured, but can easily be drawn (arts. 46, 62) on ${}_7$A, ${}_8$T, and ${}_8$W—

${}_3$A gives the solid ${}_6$J;
${}_5$A „ ${}_8$A*p*;
${}_6$F „ ${}_9$I*t*; see the three figures;
${}_7$A „ ${}_{10}$A, zo. tri. $4^4 3^6$, (446);
${}_7$C „ ${}_{10}$B, 5 zo. monch. hom. $5^2 3^{10}$, (20);
and also ${}_{10}$C, az. tri. $4^4 3^8$, (6, 14);
${}_8$R gives the solid ${}_{11}$A, 2 zo. mox. het. $4^5 3^8$, (6, 6, 10);
${}_8$A*d* „ ${}_{11}$B, 2 zo. mox. het. $5^2 4 3^{10}$, (4, 4, 14);
${}_8$A*t* „ ${}_{11}$C, moz. $54^3 3^9$, (22);
${}_9$A „ ${}_{12}$A, moz. $54^4 3^9$, (4, 20);
${}_9$B „ ${}_{12}$B, az. tri. $4^6 3^8$, (24);
${}_9$J „ ${}_{12}$C, asym. $5^2 4^2 3^{10}$, (24);
„ „ ${}_{12}$D, 6 zo. hom. $6^2 3^{12}$, (888);
${}_9$K „ ${}_{12}$E, moz. $54^4 3^9$, (10, 14);
${}_9$L „ ${}_{12}$F, 2p. mox. het. $4^6 3^8$, (6, 18);
${}_9$N „ ${}_{12}$G, 3 zo. monch. $4^6 3^8$, (6666);
${}_9$B*m* „ ${}_{12}$H, zo. triarch. $4^6 3^8$, (6, 6, 6, 6);
${}_9$D*e* „ ${}_{12}$I, 2p. mox. het. $5^2 4^2 3^{10}$, (4, 4, 16);
${}_9$E*y* „ ${}_{12}$J, 2 zo. mox. het. $5^2 4^2 3^{10}$, (10, 14);
${}_9$F*f* „ ${}_{12}$K, 2p. mox. moz. $4^6 3^8$, (24).

We have thus twenty prime solid knots, of fewer than thirteen crossings,

made on eighteen of our thirty inferior knots. The remaining twelve, viz.—

$$_6\mathrm{J}\,,\ _8\mathrm{T}\,,\ _8\mathrm{W}\,,\ _8\mathrm{A}g\,,\ _8\mathrm{A}p\,,\ _8\mathrm{A}q\,,\ \mathrm{C}_9\,,\ _9\mathrm{I}\,,\ _9\mathrm{B}n\,,\ _9\mathrm{D}l\,,\ _9\mathrm{G}d\,,\ _9\mathrm{I}t\,,$$

are found to be no bases.

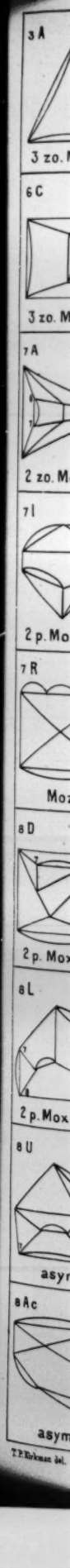
In $_{10}$A above, 4^4 means 4444, and the circles are in parentheses.

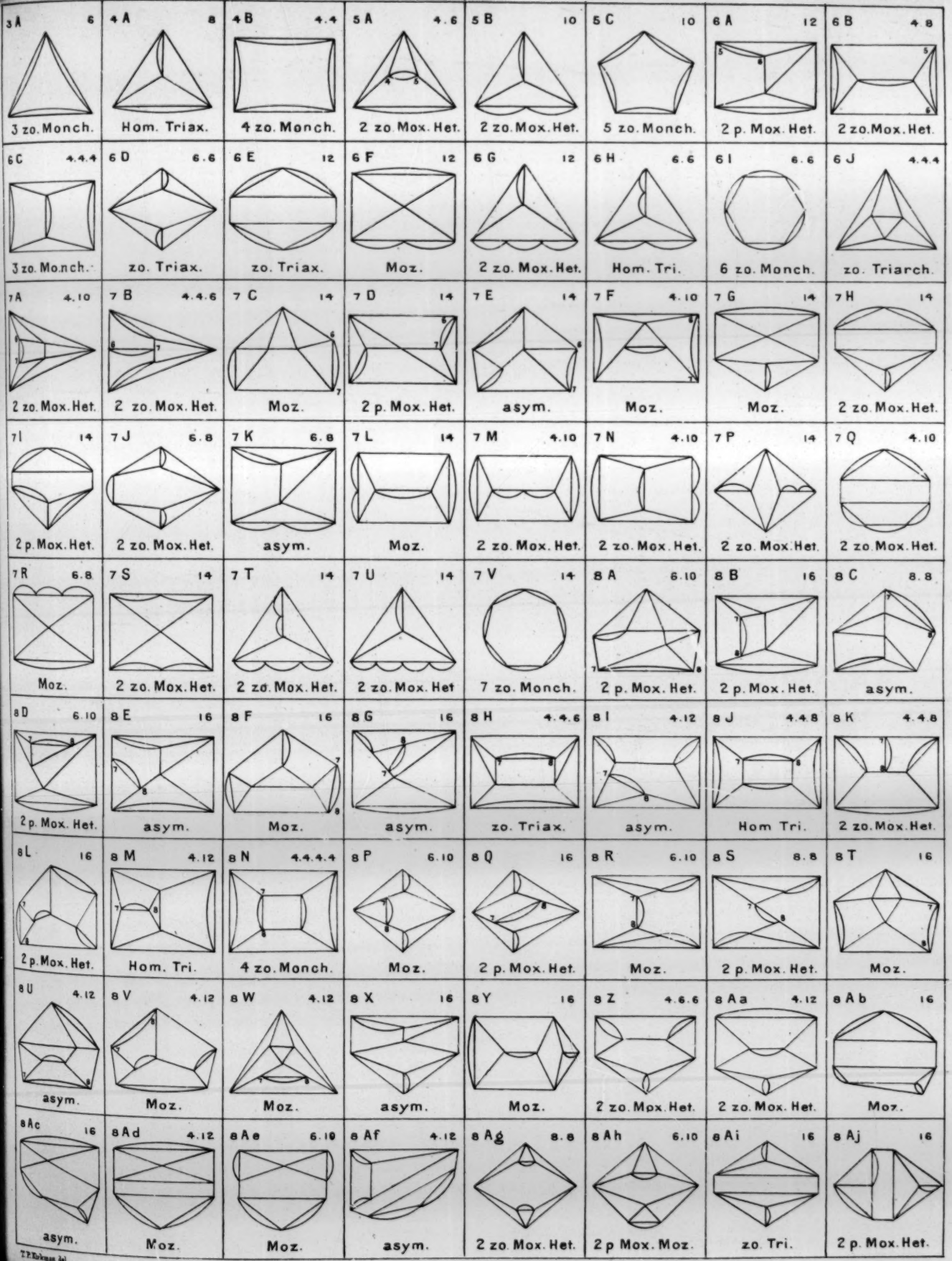
No non-prime solid knot has fewer than sixteen crossings. The simplest is $4^{10}3^8$, 4 zo. monch., in which two opposite 4-gons are each covertical with four triangles, the triangles being four pairs of collaterals.

In order that a prime solid knot P may be a base, it must have not more than three summits A3B3, which must be so placed that, by drawing a lowest triangle of the non-prime Q to be formed, every pair of covertical triangles shall disappear.

All non-primes can be easily constructed by our simple rule without omission or repetition when the primes of more than twelve crossings are before us.

This may suffice on solid knots until their value in electricity and magnetism is so enhanced as to call for a formal treatise on the whole subject.


3A
3 zo.
6C
3 zo. M
7A
2 zo. M
7I
2 p. Mo
7R
Mo
8D
2 p. Mo
8L
2 p. Mox
8U
asy
8Ac
asym
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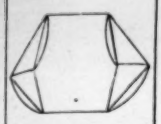
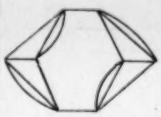
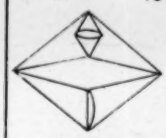
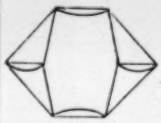
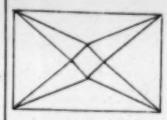
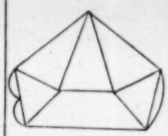
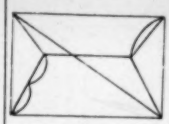
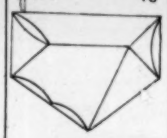
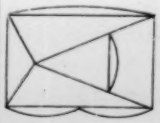
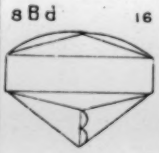
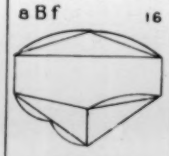
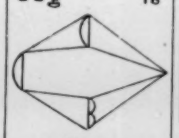
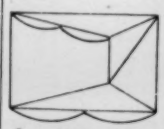
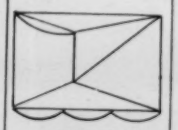
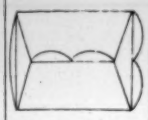
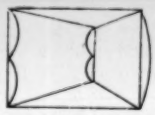
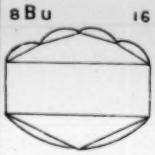
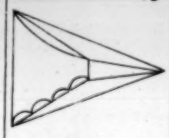
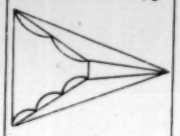
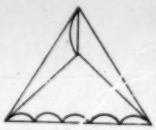
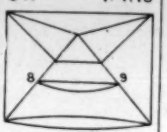
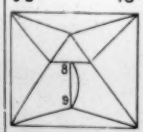
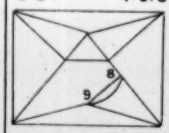
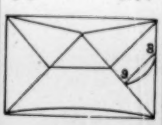
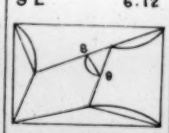
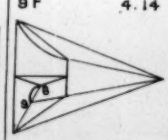
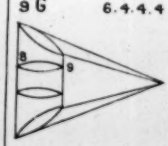
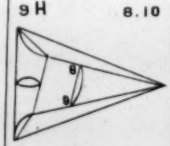
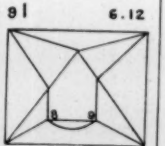
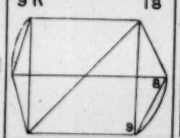
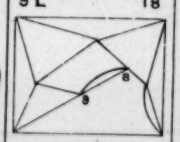
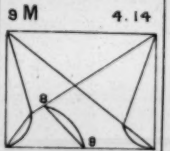
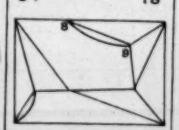
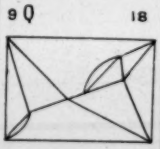
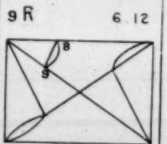
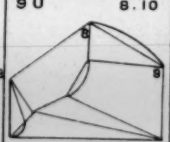
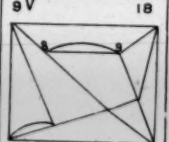
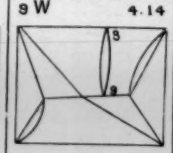
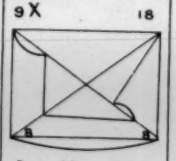
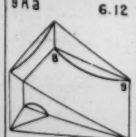
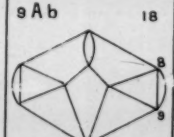
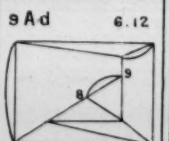
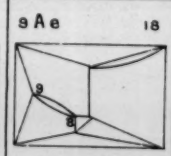
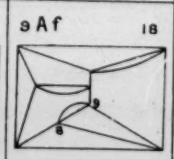
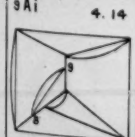
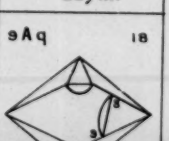
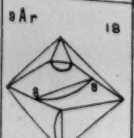
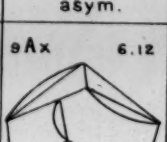


T. P. Erikson del.

P. Heath, Lith.r Edin.r

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8Ak 16  2p. Mox. Moz.	8Al 16  az. Tri.	8Am 16  Hom. Tri.	8An 8.8  zo. Tri.	8Ap 16  4 zo. Monch Hom.	8At 16  asym.	8Au 16  asym.	8Av 16  asym.
8Ax 16  asym.	8Az 16  asym.	8Bb 16  Moz.	8Bd 16  Moz.	8Bf 16  asym.	8Bg 16  Moz.	8Bi 16  2 p. Mox. Het.	8Bj 16  asym
8Bn 16  Moz.	8Bq 16  2 zo. Mox. Het.	8Bu 16  2 zo. Mox. Het.	8Bv 16  Moz.	8Bw 16  Moz.	8By 16  Hom. Tri.	8Bz 16  2 zo. Mox. Het.	9A 4.4.10  2 zo. Mox. Het.
9B 18  Moz.	9C 4.6.8  asym.	9D 4.14  Moz.	9E 6.12  Moz.	9F 4.14  Moz.	9G 6.4.4.4  2 zo. Mox. Het.	9H 8.10  Moz.	9I 6.12  Moz.
9J 18  Moz.	9K 18  2 p. Mox. Het.	9L 18  asym.	9M 4.14  asym.	9N 6.12  3 zo. Mox. Het.	9P 18  asym.	9Q 18  asym.	9R 6.12  asym.
9S 18  asym.	9T 8.10  Moz.	9U 8.10  asym.	9V 18  asym.	9W 4.14  asym.	9X 18  2 p. Mox. Het.	9Y 18  Moz.	9Z 18  2 p. Mox. Het.
9Aa 6.12  asym.	9Ab 18  Moz.	9Ac 8.10  asym.	9Ad 6.12  asym.	9Ae 18  asym.	9Af 18  asym.	9Ag 8.10  Moz.	9Ah 4.14  asym.
9Ai 4.14  asym.	9Aj 18  2 p. Mox. Het.	9Ak 18  2 p. Mox. Het.	9Al 18  Moz.	9Am 4.6.8  Moz.	9An 18  asym.	9Ap 18  asym.	9Aq 18  asym.
9Ar 18  asym.	9As 18  asym.	9At 18  asym.	9Au 18  asym.	9Av 18  asym.	9Aw 8.10  asym.	9Ax 6.12  asym.	9Ay 4.6.8  2 zo. Mox. Het.

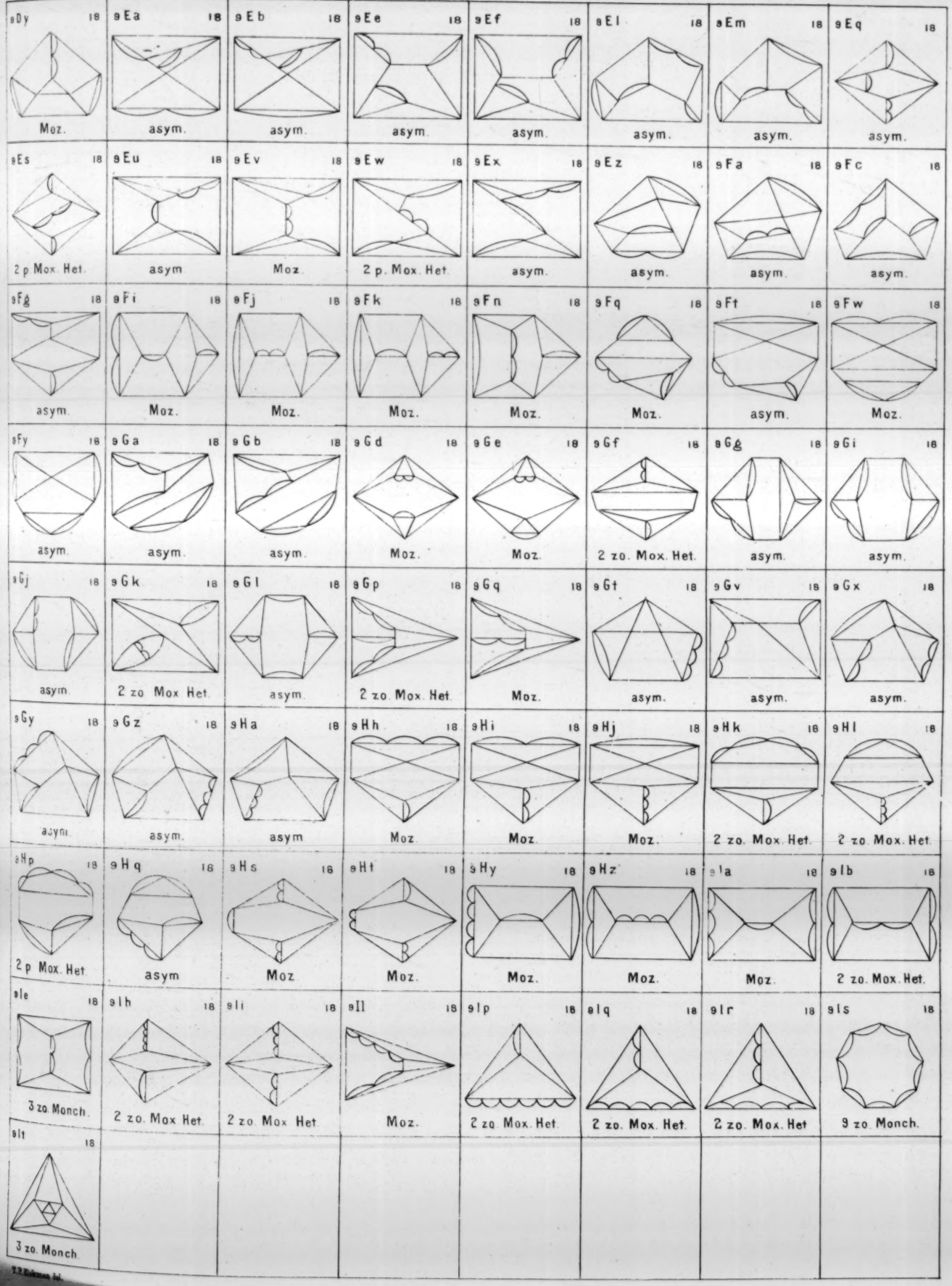
T.P. Kirkwood Ltd.

F. Huth, Lith.ʳ Edin.ʳ

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9Az 18 asym.	9Ba 6.12 asym.	9Bb 4.6.8 Moz.	9Bc 18 Moz.	9Bd 4.6.8 asym.	9Be 4.14 asym.	9Bf 4.14 asym.	9Bg 18 asym.
9Bh 4.4.10 Moz.	9Bi 4.4.10 2 zo. Mox. Het.	9Bj 4.6.8 asym.	9Bk 18 3 zo. Mox. Het.	9Bl 18 2 p. Mox. Het.	9Bm 6.12 3 zo. Mox. Het.	9Bn 4.14 Moz.	9Bp 4.14 Moz.
9Bq 6.12 2 zo. Mox. Het.	9Br 8.10 asym.	9Bs 8.10 asym.	9Bt 6.12 asym.	9Bu 18 asym.	9Bv 8.10 asym.	9Bw 18 asym.	9Bx 4.14 Moz.
9By 18 Moz.	9Bz 18 Moz.	9Ca 6.12 Moz.	9Cb 18 asym.	9Cc 6.12 asym.	9Cd 18 asym.	9Ce 18 asym.	9Cf 18 asym.
9Cg 4.6.8 Moz.	9Ch 18 Moz.	9Ci 18 Moz.	9Cj 18 Moz.	9Ck 18 asym.	9Cl 18 asym.	9Cm 8.10 Moz.	9Cn 6.12 Moz.
9Cp 4.14 Moz.	9Cq 4.6.8 Moz.	9Cr 18 asym.	9Cs 18 2 p. Mox. Het.	9Ct 18 2 p. Mox. Het.	9Cu 18 asym.	9Cv 18 asym.	9Cw 18 asym.
9Cx 4.14 Moz.	9Cy 4.14 2 zo. Mox. Het.	9Cz 4.14 Moz.	9Da 4.14 asym.	9Db 4.14 Moz.	9Dc 4.4.10 Moz.	9Dd 18 asym.	9De 4.4.10 2 zo. Mox. Het.
9Df 4.14 Moz.	9Dg 4.14 asym.	9Dh 6.12 Moz.	9Di 6.12 asym.	9Dj 18 2 zo. Mox. Het.	9Dk 18 asym.	9Dl Moz.	9Dm 2 p. Mox. Het.
9Dn 18 2 zo. Mox. Het.	9Dp 6.6.6 3 zo. Monch.	9Dq 18 asym.	9Ds 18 asym.	9Dt 18 asym.	9Du 18 asym.	9Dv 18 asym.	9Dw 18 asym.


9Dy 18
Moz.
9Ea 18
asym.
9Eb 18
asym.
9Ee 18
asym.
9Ef 18
asym.
9El 18
asym.
9Em 18
asym.
9Eq 18
asym.
9Es 18
2 p. Mox. Het.
9Eu 18
asym.
9Ev 18
Moz.
9Ew 18
2 p. Mox. Het.
9Ex 18
asym.
9Ez 18
asym.
9Fa 18
asym.
9Fc 18
asym.
9Fg 18
asym.
9Fi 18
Moz.
9Fj 18
Moz.
9Fk 18
Moz.
9Fn 18
Moz.
9Fq 18
Moz.
9Ft 18
asym.
9Fw 18
Moz.
9Fy 18
asym.
9Ga 18
asym.
9Gb 18
asym.
9Gd 18
Moz.
9Ge 18
Moz.
9Gf 18
2 zo. Mox. Het.
9Gg 18
asym.
9Gi 18
asym.
9Gj 18
asym.
9Gk 18
2 zo. Mox Het.
9Gl 18
asym.
9Gp 18
2 zo. Mox. Het.
9Gq 18
Moz.
9Gt 18
asym.
9Gv 18
asym.
9Gx 18
asym.
9Gy 18
asym.
9Gz 18
asym.
9Ha 18
asym
9Hh 18
Moz.
9Hi 18
Moz.
9Hj 18
Moz.
9Hk 18
2 zo. Mox. Het.
9Hl 18
2 zo. Mox. Het.
9Hp 18
2 p. Mox. Het.
9Hq 18
asym
9Hs 18
Moz
9Ht 18
Moz.
9Hy 18
Moz.
9Hz 18
Moz.
9Ia 18
Moz.
9Ib 18
2 zo. Mox. Het.
9Ie 18
3 zo. Monch.
9Ih 18
2 zo. Mox Het.
9Ii 18
2 zo. Mox Het
9Il 18
Moz.
9Ip 18
2 zo. Mox. Het.
9Iq 18
2 zo. Mox. Het.
9Ir 18
2 zo. Mox. Het
9Is 18
9 zo. Monch.
9It 18
3 zo. Monch

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XVIII.—*On the Approximation to the Roots of Cubic Equations by help of Recurring Chain-Fractions.* By EDWARD SANG.

(Read 7th January 1884.)

In the twenty-ninth volume of the Society's *Transactions*, at page 59, Lord BROUNCKER's process for finding the ratio of two quantities (commonly known as the method of continued fractions) is extended to the comparison of three or more magnitudes. It is there shown that *recurrence*, which was believed to belong exclusively to equations of the second degree, extends to those of higher orders, and examples of this extension are given in determining the proportions of the heptagon and enneagon.

In the present paper it is proposed to show the application of this extended method to equations of the third degree.

If there be a progression of numbers A, B, C, D, E, ... formed by means of the multipliers p, q, r, according to the scheme :—

$$\begin{aligned} rA+qB+pC&=D\\ rB+qC+pD&=E\\ rC+qD+pE&=F, \end{aligned}$$

and if the number p be greater than either q or r, the terms will approach to be in continued proportion, and their ultimate ratio will be the positive root of the equation

$$z^3-pz^2-qz-r=0, \qquad (1)$$

independently of the values assumed for the initial A, B, C. The actual progression may be regarded as the sum of three series having the initials A, 0, 0; 0, B, 0; and 0, 0, C respectively. On developing the term, we find that the coefficient of A in the nth term is r times that of C in the preceding or $n-1st$ term; while the coefficient of B is compounded of q times the $n-1st$, and r times the $n-2d$ coefficients of C. Hence we need only to compute the series beginning with 0, 0, 1, in order to have the means of compounding any term of a progression formed with the same multipliers.

The successive terms of the elementary progression are easily found to be

$$
\begin{aligned}
&[0]=1\\
&[1]=p\\
&[2]=p^2+q\\
&[3]=p^3+2pq+r\\
&[4]=p^4+3p^2q+2pr+q^2\\
&[5]=p^5+4p^3q+3p^2r+3pq^2+2qr\\
&[6]=p^6+5p^4q+4p^3r+6p^2q^2+6pqr+q^3+r^2\\
&[7]=p^7+6p^5q+5p^4r+10p^3q^2+12p^2qr+4pq^3+3pr^2+3q^2r\\
&[8]=p^8+7p^6q+6p^5r+15p^4q^2+20p^3qr+10p^2q^3+6p^2r^2+12pq^2r+q^4+3qr^2\\
&\quad .\quad .\quad .\quad .\quad .\quad .\quad .\quad .\quad .\quad .\quad .\quad .\quad .\quad .
\end{aligned}
$$

and the general form of the nth term of the progression having the initials A, B, C, is, C being regarded as the zero term,

$$[n-1]r\mathrm{A}+\{[n-1]q+[n-2]r\}\mathrm{B}+[n]\mathrm{C}$$

or

$$[n-2]r\mathrm{B}+[n-1]\{r\mathrm{A}+q\mathrm{B}\}+[n]\mathrm{C}.$$

But the elementary progression alone suffices to determine the value of the ultimate ratio $1:x$.

This process is applicable directly only to equations having suitable coefficients. In the case of pure equations, those whose quæsitum is the cube root of some number, the coefficients p and q are both zeroes, and the progression becomes

$$0,\ 0,\ 1,\ 0,\ 0,\ r,\ 0,\ 0,\ r^2,\ 0,\ 0,\ r^3,\ \&c.,$$

which contains the truism that the ratio $1:r$; $r:r^2$; is triplicate of that of which we are in search.

In order so to change the form of an equation as to fit it for the application of this method, we modify LAGRANGE'S process in a manner which may be best explained by examples.

Let it be proposed to extract the cube root of the number 2.

In the equation

$$x^3-0x^2-0x-2=0,$$

we may write $\frac{a}{b}$ in place of x, so as to give to it the form

$$a^3-0a^2b-0ab^2-2b^3=0,$$

in which, if b represent the side of a cube, a stands for the side of the double cube.

Here, in order to find the ratio of a to b, we, following BROUNCKER's plan, try how often b is contained in a. Clearly it is only once, with something over. We therefore write $a=1b+c$, and get, by substitution,

$$1b^3-3b^2c-3bc^2-c^3=0,$$

an equation easily managed. The ratio of c to b is now obtained from a progression regulated by the multipliers $r=1$, $q=3$, $p=3$; thus

$$0,\ 0,\ 1,\ 3,\ 12,\ 46,\ 177,\ 681,\ 2\,620,\ 10\,080,\ \&c.;$$

so that if any one term—say 177—be assumed for c, the succeeding term, 681, is approximately the corresponding value of b; but $a=1b+c$, wherefore 858 is the corresponding value of a. In this way we form the series—

	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\frac{1}{0}$,	$\frac{0}{0}$,	$\frac{1}{1}$,	$\frac{4}{3}$,	$\frac{15}{12}$,	$\frac{58}{46}$,	$\frac{223}{177}$,	$\frac{858}{681}$,	$\frac{3\,301}{2\,620}$,	$\frac{12\,700}{10\,080}$,	$\frac{44\,861}{38\,781}$,

(10)	(11)	(12)	(13)	(14)	(15)	
$\frac{187\,984}{149\,203}$,	$\frac{723\,235}{571\,032}$,	$\frac{2\,782\,518}{2\,208\,486}$,	$\frac{10\,705\,243}{8\,496\,757}$,	$\frac{41\,186\,518}{32\,689\,761}$,	$\frac{158\,457\,801}{125\,768\,040}$,	&c.,

approaching very rapidly to the cube root of 2.

Among these we notice that each member of the terms (3), (6), (9), (12), (15) is divisible by 3. On simplification, these terms, with the prefixes $\frac{+1}{-1}$, $\frac{0}{0}$, form a series progressing according to the scheme $r=1$, $q=-3$, $p=57$; thus

	(0)	(1)	(2)	(3)	(4)	(5)
$\frac{+1}{-1}$,	$\frac{0}{0}$,	$\frac{5}{4}$,	$\frac{286}{227}$,	$\frac{16\,287}{12\,927}$,	$\frac{927\,506}{736\,162}$,	$\frac{52\,819\,267}{41\,922\,680}$,

converging still more rapidly to the required root. The term (2) is true to within the accuracy of five-place logarithms, the defect being ·000 0032. The next term (3) passes beyond the exactitude of seven-place tables, its logarithm being in excess by ·00000 00157. The excess in the case of (4) is ·00000 00000 31409, which could not be detected with the ten-place tables; while (5) gives a defect of ·00000 00000 00053, as tested by my manuscript tables to fifteen places. The errors are two in defect, two in excess, and so on.

The roots of numbers immediately above or below a cube are very readily found. Thus for the cube root of 9 the equation becomes $a^3-9b^3=0$; whence $a=2b+c$, and

$$b^3-12b^2c-6bc^2+1c^3=0.$$

Hence for a progression converging to the ratio $b : c$ we have the multipliers $r=1$, $q=6$, $p=12$, giving the series

$$0,\ 0,\ 1,\ 12,\ 150,\ 1\,873,\ 23\,388,\ \&c.;$$

and hence, converging to the ratio of $a : b$, we have the progression

$$\begin{array}{cccccccccc} & (0) & (1) & (2) & (3) & (4) & (5) & (6) & (7) & (8) \\ \frac{1}{0}, & \frac{0}{0}, & \frac{2}{1}, & \frac{25}{12}, & \frac{312}{150}, & \frac{3\,896}{1\,873}, & \frac{48\,649}{23\,388}, & \frac{607\,476}{292\,044}, & \frac{7\,855\,502}{3\,646\,729}, & \frac{94\,719\,529}{45\,536\,400}, \end{array}$$

$$\begin{array}{ccccc} (9) & & (10) & & (11) & & (12) & & \\ \frac{1\,182\,754\,836}{568\,609\,218}, & & \frac{14\,768\,960\,708}{7\,100\,175\,745}, & & \frac{184\,418\,777\,041}{88\,659\,300\,648}, & & \frac{2\,302\,821\,843\,576}{1\,107\,081\,271\,464}, & & \&c. \end{array}$$

Here the terms (3), (6), (9), (12) are reducible by the common divisor 6, and form the progression

$$\begin{array}{ccccccc} & (0) & (1) & (2) & (3) & (4) & \\ \frac{2}{-1}, & \frac{0}{0}, & \frac{52}{25}, & \frac{101\,246}{48\,674}, & \frac{197\,125\,806}{94\,768\,203}, & \frac{383\,803\,640\,596}{184\,513\,545\,244}, & \end{array}$$

which proceeds according to the multipliers $r=1$, $q=-3$, $p=1947$.

This convergence is so rapid that the error of the term (2) cannot be detected by help of the ten-place logarithms; that of (3) is beyond the precision of the fifteen-place tables.

In the case of the number 7, which is less by unit than the cube of 2, the convergence is somewhat slower. For the equation

$$a^3-7b^3=0$$

it is convenient to take the first measure in excess, and to write $a=2b-c$, which gives

$$b^3-12b^2c+6bc^2-c^3=0;$$

so that the progression, by help of the multipliers $r=1$, $q=-6$, $p=12$, becomes

$$\begin{array}{cccccccccc} & (0) & (1) & (2) & (3) & (4) & (5) & (6) & (7) & \\ \frac{-1}{0}, & \frac{0}{0}, & \frac{2}{1}, & \frac{23}{12}, & \frac{264}{138}, & \frac{3\,032}{1\,585}, & \frac{34\,823}{\quad}, & \frac{399\,948}{209\,076}, & \frac{4\,593\,470}{2\,401\,273}, & \end{array}$$

$$\begin{array}{ccccccc} (8) & & (9) & & (10) & & (11) & & (12) & & \\ \frac{52\,756\,775}{27\,579\,024}, & & \frac{605\,920\,428}{316\,749\,726}, & & \frac{6\,959\,097\,956}{3\,637\,923\,841}, & & \frac{79\,926\,409\,679}{41\,782\,166\,760}, & & \frac{917\,968\,248\,840}{479\,875\,207\,800}, & & \&c., \end{array}$$

of which the terms (3), (6), (9), (12) give, on being simplified, the progression

$$\begin{matrix} & (0) & (1) & (2) & (3) & (4) \\ \frac{-2}{1}, & \frac{0}{0}, & \frac{44}{23}, & \frac{66\,658}{34\,846}, & \frac{100\,986\,738}{52\,791\,621}, & \frac{152\,994\,708\,140}{79\,979\,201\,300}, \end{matrix}$$

for which the multipliers are $r=1$, $q=-3$, and $p=1515$.

In order to get a clear view of the general principles here involved, we shall propose to extract the cube root of n^3+1.

The equation $a^3-(n^3+1)b^3=0$, gives, for the first approximation, $a=nb+c$, whence

$$b^3-3n^2b^2c-3nbc^2-c^3=0,$$

so that the multipliers are $r=1$, $q=3n$, $p=3n^2$, which give, converging to the ratio of $b:c$, the progression

$$0,\ 0,\ 1,\ 3n^2,\ 9n^4+3n,\ 27n^6+18n^3+1,\ \&c.,$$

and consequently, converging to $\sqrt{(n^3+1)}$, the series of fractions

$$\begin{matrix} & (0) & (1) & (2) & (3) & (4) \\ \frac{1}{0}, & \frac{0}{0}, & \frac{n}{1}, & \frac{3n^3+1}{3n^2}, & \frac{9n^5+6n^2}{9n^4+3n}, & \frac{27n^7+27n^4+4n}{27n^6+18n^3+1}, \end{matrix}$$

$$\begin{matrix} (5) & (6) \\ \frac{81n^9+108n^6+33n^2+1}{81n^8+81n^5+15n^2}, & \frac{243n^{11}+405n^8+189n^5+21n^2}{243n^{10}+324n^7+108n^4+6n}, \end{matrix}$$

$$(7)\qquad \frac{729n^{13}+1\,458n^{10}+918n^7+189n^4+7n}{729n^{12}+1\,215n^9+594n^6+81n^3+1},$$

$$(8)\qquad \frac{2\,187n^{15}+5\,103n^{12}+4\,050n^9+1\,242n^6+117n^3+1}{2\,187n^{14}+4\,374n^{11}+2\,835n^8+648n^5+36n^2},$$

$$(9)\qquad \frac{6\,561n^{17}+17\,496n^{14}+16\,767n^{11}+6\,885n^8+1\,107n^5+45n^2}{6\,561n^{16}+15\,309n^{13}+12\,393n^{10}+4\,050n^7+459n^4+9n}.$$

Here we observe that the numerators of the terms (3), (6), (9) are divisible

by $3n^2$, the denominators by $3n$, and hence, for the value of $\frac{\sqrt[3]{(n^3+1)}}{n}$ there comes out the progression

$$\frac{+1}{-1}, \quad \frac{0}{0}, \quad \frac{3n^3+2}{3n^3+1}, \quad \frac{81n^9+135n^5+63n^3+7}{81n^9+108n^6+36n^3+2},$$

$$\frac{2\,187n^{15}+5\,832n^{12}+5\,589n^9+2\,295n^6+369n^3+15}{2\,187n^{15}+5\,103n^{12}+4\,131n^9+1\,350n^6+153n+3},$$

the multipliers for which are

$$r=1,\ q=-3,\ p=27n^6+27n^3+3,$$

and similarly we find for $\frac{\sqrt[3]{(n^3-1)}}{n}$, the multipliers to be

$$r=1,\ q=-3,\ p=272^6-27n^3+3,$$

with the initial terms

$$\frac{-1}{+1}, \quad \frac{0}{0}, \quad \frac{3n^3-2}{3n^3-1},$$

these results agreeing with what has been found in the cases of 9 and of 7.

It may also be observed that each third term of these second series is reducible by 3, and that they form a progression converging still more rapidly.

When the proposed number differs from a complete cube by more than unit the extraction of the root is more complicated. As an example, we shall take the number 3.

In the equation $a^3-3b^3=0$, on putting $a=1b+c$ we get

$$-2b^3+3b^2c+3bc^2+1c^3=0,$$

or

$$b^2-\frac{3}{2}b^2c-\frac{3}{2}bc^2-\frac{1}{2}c^3=0,$$

whence the multipliers

$$r=\frac{1}{2},\ q=\frac{3}{2},\ p=\frac{3}{2}$$

or, more conveniently

$$r=\frac{4}{8},\ q=\frac{6}{4},\ p=\frac{3}{2},$$

from which the progression

$$0,\ 0,\ 1,\ \frac{3}{2},\ \frac{15}{4},\ \frac{67}{8},\ \frac{303}{16},\ \frac{1\,371}{32},\ \frac{6\,199}{64},\ \frac{28\,035}{128},\ \&c.,$$

the numerators being got from the multipliers 4, 6, 3, while the denominators are powers of 2. From this, since $a=b+c$, we have the approximations to $\sqrt{3}$

(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\frac{0}{0}$,	$\frac{1}{1}$,	$\frac{5}{3}$,	$\frac{21}{15}$,	$\frac{97}{67}$,	$\frac{437}{303}$,	$\frac{1\,977}{1\,371}$,	$\frac{8\,941}{6\,199}$,	$\frac{40\,433}{28\,035}$,	$\frac{182\,853}{126\,783}$,

(10)	(11)	(12)	
$\frac{826\,921}{573\,355}$,	$\frac{3\,739\,613}{2\,592\,903}$,	$\frac{16\,911\,777}{11\,725\,971}$,	&c.

Here, as in the preceding cases, each third term may be simplified, the progression being

$$\frac{0}{0},\ \frac{7}{5},\ \frac{659}{457},\ \frac{60\,951}{42\,261},\ \frac{5\,637\,259}{3\,908\,657},\ \text{&c.},$$

for which the multipliers are $r=64$, $q=-48$, $p=98$.

Here the approximation is comparatively slow, the less accurate terms being largely combined with the more accurate ones.

To carry BROUNCKER'S process one step farther, let us try how often b contains c; for $b=1c$, the above equation gives $+5c^3$ instead of zero; for $b=2c$, the result is $+3c^3$; but for $b=3c$, we get $-17c^3$, wherefore b contains c twice with something over; we therefore write $b=2c+d$. The substitution gives

$$+3c^3-9c^2d-9cd^2-2d^3=0,$$

or

$$c^3-3c^2d-3cd^2-\frac{2}{3}d^3=0.$$

The multipliers hence resulting are

$$r=\frac{2}{3},\ q=3,\ p=3,$$

giving the progression for $d:c$

$$0,\ 0,\ 1,\ 3,\ 12,\ 45\frac{2}{3},\ 175,\ 670,\ 2\,565\frac{4}{9},\ \text{&c.},$$

but $a=3c+d$, $b=2c+d$, wherefore the ratio of $a:b$ is given by the progression

$$\begin{array}{cccccccc} (0) & (1) & (2) & (3) & (4) & (5) & (6) & (7) \\ \frac{0}{0}, & \frac{3}{2}, & \frac{10}{7}, & \frac{39}{27}, & \frac{149}{103\frac{1}{3}}, & \frac{570\frac{2}{3}}{395\frac{2}{3}}, & \frac{2\,185}{1\,515}, & \frac{8\,366\frac{1}{2}}{5\,800\frac{2}{3}}, \end{array}$$

$$\begin{array}{ccccc} (8) & (9) & (10) & (11) & (12) \\ \frac{32\,034\frac{4}{5}}{22\,211\frac{4}{5}}, & \frac{122\,659}{85\,047}, & \frac{469\,657\frac{8}{9}}{325\,622\frac{1}{2}\frac{8}{7}}, & \frac{1\,798\,306\frac{2}{3}\frac{9}{7}}{1\,246\,806\frac{1}{2}\frac{1}{7}}, & \frac{6\,885\,667\frac{2}{3}}{4\,774\,255}, \text{ &c.,} \end{array}$$

converging much more rapidly.

LAGRANGE'S application of BROUNCKER'S method may be still farther continued, as in the following scheme :—

$$\begin{array}{rlll} 0 = & a^3 - 0a^2b - 0ab^2 - 3b^3 ; & a = 1b + c ; \\ 0 = - & 2b^3 + 3b^2c + 3bc^2 + 1c^3 ; & b = 2c + d ; \\ 0 = + & 3c^3 - 9c^2d - 9cd^2 - 2d^3 ; & c = 3d + e ; \\ 0 = - & 29d^3 + 18d^2e + 18de^2 + 3e^3 ; & d = 1e + f ; \\ 0 = + & 10e^3 - 33e^2f - 69ef^2 - 29f^3 ; & e = 4f + g ; \\ & \text{&c.} & \text{&c.} \end{array}$$

until we arrive at some equation promising greater facility or greater rapidity. The last of the above gives

$$r = 2.9 ; \; q = 6.9 ; \; p = 3.3 ;$$

with the condition $a = 13e + 10f$; $b = 9e + 7f$.

For the cube root of the next number, 4, we have

$$\begin{array}{rlll} & a^3 - 0a^2b - 0ab^2 - 4b^3 = 0, & a = 1b + c ; \\ - & 3b^3 + 3b^2c + 3bc^2 + 1c^3 = 0 ; & b = 1c + d ; \\ + & 4c^3 - 0c^2d - 6cd^2 - 3d^3 = 0 ; & c = 1d + e ; \\ - & 5d^3 + 6d^2e + 12de^2 + 4e^3 = 0 ; & d = 2e + f ; \\ + & 12e^3 - 24e^2f - 24ef^2 - 5f^3 = 0 ; & e = 2f + g ; \\ - & 53f^3 + 24f^2g + 48fg^2 + 12g^3 = 0 ; & f = 1g + h ; \\ + & 31g^3 - 63g^2h - 135gh^2 - 53h^3 = 0 ; & g = 3h + i ; \\ & -188h^3 + 324h^2i + 216hi^2 + 31i^3 = 0 ; & h = 2i + k ; \\ & \text{&c.} & \text{&c.} \end{array}$$

The equation in e and f put in the form

$$e^2 - 2e^2f - 2ef^2 - \frac{5}{12}f^3 = 0 ,$$

gives the multiplications $r = \frac{5}{21}$, $q = 2$, $p = 2$, and these, along with the conditions

$$a = 3e + 3f ; \; b = 5e + 2f ;$$

produce the progression

$$\frac{8}{5},\ \frac{19}{12},\ \frac{54}{34},\ \frac{149\frac{4}{12}}{94\frac{1}{12}},\ \frac{414\frac{7}{12}}{261\frac{2}{12}},\ \frac{1\,150\frac{1}{3}}{724\frac{2}{3}},\ \text{&c.},$$

converging rapidly to the value of $\sqrt[3]{4}$.

For the cube root of 5 the equations are

$$\begin{array}{rrrrl}
a^3- & 0a^2b- & 0ab^2- & 5b^3=0\,; & a=1b+c\,;\\
-\ 4b^3+ & 3b^2c+ & 3bc^2+ & 1c^3=0\,; & b=1c+d\,;\\
+\ 3c^3- & 3c^2d- & 9cd^2- & 4d^3=0\,; & c=2d+e\,;\\
-10d^3+ & 15d^2e+ & 15de^2+ & 3e^3=0\,; & d=2e+f\,;\\
+13e^3- & 45e^2f- & 45ef^2-10f^3=0\,; & & e=4f+g\,;\\
-78f^3+219f^2g+111fg^2+13g^3=0\,; & & & & f=3g+h\,;\\
\text{&c.} & & & & \text{&c.}
\end{array}$$

The equation in d and e gives the multipliers

$$r=.3\,;\ q=1.5\,;\ p=1.5\,;$$

while $a=5d+2e\,;\ b=3d+1e\,;$ hence for $\sqrt[3]{5}$, we have the progression

$$\frac{5}{3},\ \frac{9.5}{5.5},\ \frac{21.75}{12.75},\ \frac{48.375}{28.275},\ \frac{108.0375}{63.1875},\ \frac{241.14375}{141.01875},\ \frac{538.284375}{314.791875},\ \text{&c.}$$

Here the error is reduced about 5 times at each successive step.

The equation in e and f gives

$$r=\frac{1\,690}{13^3}\,;\ q=\frac{585}{13^2}\,;\ p=\frac{45}{13}\,;$$

while $a=12e+5f\,;\ b=7e+3f\,.$

The progression thence resulting is

$$\frac{12}{7},\ \frac{605}{354},\ \frac{34\,245}{20\,025},\ \frac{1\,915\,230}{1\,120\,045},\ \frac{107\,241\,125}{62\,714\,910},\ \text{&c.},$$

converging more rapidly than the former.

From these instances it is clear that the cube root of any number, or the root of any cubic equation with integer coefficients, may be represented by a series of chain-fractions of the third order; and not by one only, but by many of such series. Since the successive steps of the Brounckerian process necessarily depends on the peculiarities of the case, it would be difficult to make a general analysis beyond the first step; but a symbolical investigation that far may lead to important results.

Let us take the general case of a number exceeding a perfect cube by, say, a; that is a number of the form n^3+a. We have here $a=nb+c$, and the equation

$$c^3-(n^3+a)b^3=0$$

becomes

$$-ab^3+3n^2bc+3nbc^2+c^3=0\,,$$

which gives the multipliers

$$r=\frac{1}{a}\,;\ q=\frac{3n}{a}\,;\ p=\frac{3n^2}{a}\,;$$

or more conveniently

$$r=\frac{a^2}{a^3}\,;\ q=\frac{3an}{a^2}\,;\ p=\frac{3n^2}{a}\,;$$

from which we have the elementary progression

$$0,\ 0,\ 1,\ \frac{3n^2}{a},\ \frac{9n^4+3an}{a^2},\ \frac{27n^6+18an^3+a^2}{a^3},\ \&c.,$$

and thence the progression of fractions

$$\frac{a^{-1}}{.0}\ \ \frac{0}{0},\ \frac{3n^3+a}{3n^2},\ \frac{9n^5+6an^2}{9n^4+3an},\ \frac{27n^6+27an^3+4a^2}{27n^6+18an^3+a^2},$$

following exactly the law of those already found when the excess a is unit; the multipliers being a^2, $3an$, $3n^2$.

By a proceeding exactly analogous to that formerly used, we find that the convergence to the cube root of the ratio $n^3-a : n^3$, is obtained from a progression of which the multipliers are

$$r=a^6\,;\ q=-3a^4\,;\ p=27n^6+27an^3+3a^2,$$

the initials being

$$\frac{+a^{-3}}{-a^{-3}}\,;\ \frac{0}{0}\,;\ \frac{3n^3+2a}{3n^3+1a}.$$

This formula may be generalised by substituting for n^3 any number K. Then $\sqrt[3]{\frac{K+a}{K}}$ is obtained with the multipliers

$$a^6\,;\ -3a^4\,;\ 27K^2+27aK+3a^2$$

from the initial terms

$$\frac{+a^{-3}}{-a^{-3}}\,;\ \frac{0}{0}\,;\ \frac{3K+2a}{3K+1a}.$$

And again, if we write $K+a=L$ or $a=L-K$, $\sqrt[3]{\frac{L}{K}}$ results, with the multipliers,

$$(L-K)^6;\ 3(L-K^4;\ 3L^2+21KL+3K^2;$$

from the initials

$$\frac{+(L-K^{-3}}{-(L-K^{-3}};\ \frac{0}{0};\ \frac{K+2L}{2K+L};\ \frac{2K^3+30K^2L+42KL^2+7L^3}{7K^3+42K^2L+30KL^2+2L^3}.$$

These inquiries have been confined to the components of two terms only of the elementary progression, whereas in chain-fractions of the third order three terms are admissible. For the purpose then of giving the utmost generality to our research we shall suppose the three initial terms of a progression to be

$$\frac{A}{\alpha},\quad \frac{B}{\beta},\quad \frac{C}{\gamma},$$

the multipliers being, as before, r, q, p. Then, according to what has been already shown, the nth subsequent terms is

$$\frac{[n-2]rB+[n-1]\{rA+qB\}+[n]C}{[n+2]r\beta+[n-1]\{r\alpha+q\beta\}+[n]\gamma}.$$

If then x be the asymptote of the elementary progression, while S is that of the series of fractions, we must have

$$\frac{rB+(rA+qB)x+Cx^2}{r\beta+(r\alpha+q\beta)x+\gamma x^2}=S; \quad \ldots\ldots\ldots\ldots (2)$$

and we wish now to express S directly in terms of the nine data, A, B, C; α, β, γ; p, q, r. For this purpose we must eliminate x from the two equations (1) and (2).

Equation (2) may be written in the form

$$(C-\gamma S)x^2+\{r(A-\alpha S)+q(B-\beta S)\}x+r(B-\beta S)=0 \quad \ldots\ldots (2)$$

from which and

$$x^3-px^2-qx-r=0 \quad \ldots\ldots\ldots\ldots (1)$$

we have to eliminate x. The elimination gives

$$
\begin{aligned}
&S^3\{r^2\alpha^3+2qr\alpha^2\beta+pr\alpha^2\gamma+(pr+q^2)\alpha\beta^2+(pq-3r)\alpha\beta\gamma-q\alpha\gamma^2+(pq+r)\beta^3\\
&\quad+(p^2-q)\beta^2\gamma-2p\beta\gamma^2+\gamma^3\}\\
&-S^2\{A[3r^2\alpha^2+4qr\alpha\beta+2pr\alpha\gamma+(pr+q^2)\beta^2+(pq-3r)\beta\gamma-q\gamma^2]\\
&\quad+B[2qr\alpha^2+(2pr+2q^2)\alpha\beta+(pq-3r)\alpha\gamma+(3pq+3r)\beta^2+(2p^2-2q)\beta\gamma-2p\gamma^2]\\
&\quad+C[pr\alpha^2+(pq-3r)\alpha\beta-2q\alpha\gamma+(p^2-q)\beta^2-4p\beta\gamma+3\gamma^2]\}\\
&+S\{\alpha[3r^2A^2+4qrAB+2prAC+(q^2+pr)B^2+(pq-3r)BC-qC^2]\\
&\quad+\beta[2qrA^2+(2pr+2q^2)AB+(pq-3r)AC+(3pq+3r)B^2+(2p^2-2q)BC-2pC^2]\\
&\quad+\gamma[prA^2+(pq-3r)AB-2qAC+(p^2-q)B^2-4pBC+3C^2]\}\\
&-S^0\{r^2A^3+2qrA^2B+prA^2C+(pr+q^2)AB^2+(pq-3r)ABC-9AC^2+(pq+r)B^3+\\
&\quad(p^2-q)B^2C-2pBC^2+C^3\}=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)
\end{aligned}
$$

Thus it appears that, while the root of every cubic equation may be reached by help of a recurring chain-fraction of the third order, every such fraction has for its asymptote the root of a cubic. The above equation (3) gives us directly the form of the cubic when the initials and the scheme of progression are known; and, inversely, it contains the means for discovering the progression suiting a proposed cubic. Thus for such an equation as

$$GS^3-HS^2+KS-L=0,$$

we must equate the above coefficients to G, H, K, L respectively. Here, among the nine unknowns, p, q, r; A, B, C; α, β, γ, we have only four conditions, so that we are at liberty to make five arbitrary assumptions. Now of the six, A, B, C; α, β, γ, the third power of each occurs; hence the ultimate equation must contain at least one cube. Thus we are again thrown back on the solution of a cubic; but in this case we know that it is always possible so to make the assumptions as that the root may be integer, provided the coefficients of the given equation be so.

The preceding very involved expressions may be replaced by others considerably simpler. The nth term of the progression may be written

$$\frac{D[n]+E[n-1]+F[n-2]}{d[n]+e[n-1]+F[n-2]},$$

where D takes the place of rB, E that of $(r$A$+q$B$)$, and F that of C; and similarly for the denominator. The asymptote then is

$$\frac{Dx^2+Ex+F}{dx^2+ex+f}=S$$

whence

$$(D-dS)x^2+(E-eS)x-(F-f)x=0.$$

The elimination now gives

$$S^3\{r^3d^3-qrd^2e+(q^2-2pr)d^2f+prde^2-(pq+3r)def+(p^2+2q)df^2+re^3-qe^2f+pef^2+f^3\}$$

$$-S^2\{3r^3Dd^2-qr(2Dde+Ed^2)+(q^2-2pr)(2Ddf+Fd^2)+pr(De^2+2Ede)-(pq+3r)(Def+Edf+Fde)+(p^2+2q)(Df^2+2Fdf)+3rEe^2-q(2Eef+Fe^2)+p(Ef^2+2Fef)+3Ff^2\}$$

$$+S^1\{3r^3D^2d-qr(D^2e+2DEd)+(q^2-2pr)(D^2f+2DFd)+pr(2DEe+E^2d)-(pq+3r)(DEf+DFe+EFd)+(p^2+2q)(2DFf+F^2d)+3rE^2e-q(E^2f+2EFe)+p(2EFf+F^2e)+3F^2f\}$$

$$-S^0\{r^3D^3-qrD^2E+(q^2-2pr)D^2F+prDE^2-(pq+3r)DEF+(p^2+2q)DF^2+rE^3-qE^2F+pEF^2+F^3\}=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

It may be interesting to apply this method to some problems in geometry; and we may take the construction of the heptagon as a first example.

The ratio of the diagonal to the side of a regular pentagon is given by the well-known series 0, 1, 1, 1, 2, 3, 5, 8, 13, 21, &c., in which each term is the sum of the two preceding, this being a progression of the second order having the multipliers $q=1$, $p=1$.

The relation between the long diagonal, a, and the side, b, of a heptagon is easily shown to be

$$a^3-2a^2b-ab^2+b^3=0,$$

which gives at once the multipliers $r=1$, $q=+1$, $p=2$, whence the progression

$$0, 0, 1, 2, 5, 11, 25, 56, 126, 283, 636, \&c.,$$

each new term being the double of the last found together with the difference between the preceding terms. The convergence here is slow; to make it more rapid we may write $a=2b+c$, and so get the equation

$$-b^3+3b^2c+4bc^2+c^3=0.$$

This gives the multipliers $r=1$, $q=4$, $p=3$; whence the progression

$$\frac{1}{0}, \frac{0}{0}, \frac{2}{1}, \frac{7}{3}, \frac{29}{13}, \frac{117}{52}, \frac{474}{211}, \&c.,$$

and a still more rapid convergence is obtained by putting $b=4c+d$; we then find

$$c^3-20c^2d-9cd^2-d^3=0,$$

while

$$a=9c+2d,\ b=4c+1d.$$

Here $r=1$, $q=9$, $p=20$, and the rapidly converging series is

$$\frac{2}{1},\ \frac{0}{0},\ \frac{9}{4},\ \frac{182}{81},\ \frac{3\,721}{1\,656},\ \frac{76\,067}{33\,853},\ \frac{185\,805}{82\,691},\ \&c.$$

Enneagon.

If we contract an isosceles triangle, having each angle at the base quadruple of the angle at the vertex, and if we lay off along the side two parts, each equal to the base, and from the vertex one part, the three measures overlap by a distance easily shown to be the fourth term of a continued proportion, of which the side and the base are the first and second terms.

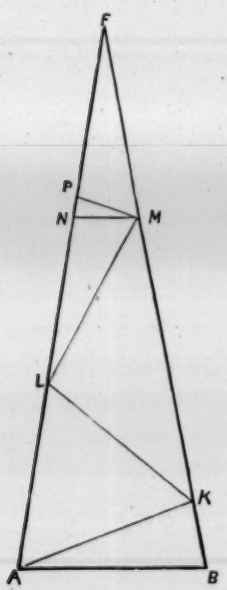
Hence, if a be the long diagonal of an enneagon, and b the side,

$$a^2 : b^2 :: b : 3b-a,$$

or

$$a^3-8a^2b+b^3=0.$$

This equation gives at once a series having $r=-1$, $q=0$, $p=3$ for the multipliers, viz.—



0, 0, 1, 3, 9, 26, 75, 216, 622, 1 791, 5 157, &c.,

which converges pretty rapidly to the ratio of the base to the long diagonal. Here, from thrice the term last found, we subtract the ante-penult, in order to get a new term; that is, from thrice AB we subtract PN to obtain AF. From thrice AF we should subtract KB to get the long diagonal of an enneagon having FA for its side, and so on, the distances PN, KB, BA, AF being in continued proportion.

The figures FMNP and FABK are evidently similar; so if in the continued direction FB we measure from K, twice FB, to M′, we shall obtain an enlarged edition of the figure FMNP.

The convergence becomes more rapid if we put $a=3b-c$, so as to get the equation

$$b-9b^2c+6bc-c^3=0.$$

The multipliers $r=1$, $q=-6$, $p=9$ thus found give the progression

$$\frac{-1}{0},\ \frac{0}{0},\ \frac{3}{1},\ \frac{26}{9},\ \frac{216}{75},\ \frac{1\,791}{622},\ \frac{14\,849}{5\,157},\ \&c.,$$

which contains each alternate term of the preceding.

The construction of a regular polygon of eleven sides involves an equation of the fifth order, and would introduce chain-fractions also of that order. The extension of the present method to that case offers no difficulty, but would pass beyond the scope of this paper.

In the preceding examples we have several times examined the progression formed by each third term of the series; and in the last example we have noticed the progression of the alternate terms. This brings us to the general law, that the terms taken at equal intervals along a series of recurring chain-fractions form a series of the same kind. Thus [0], [2], [4], [6], &c., are connected by the law

$$[n-4]\{r^2\}\times[n-2]\{2pr-q^2\}+[n]\{p^2+2q\}=[n-2],$$

the multipliers being

$$R=r^2,\ Q=2pr-q^2,\ P=p^2+2q.$$

And, similarly each third term forms a progression according to the law

$$[n-6]\{r^3\}+[n-3]\{q^3-3pqr-3r^2\}-[n]\{p^3+3pq+3r\}=[n+3],$$

where

$$R=r^3;\ Q=q^2-3pqr-3r^2;\ P=p^3+3pq+3r.$$

In the same way, for the terms four steps apart, we have

$$R=-r^4;\ Q=-2p^2r^2+4pq^2r-q^4+4qr^2;$$
$$P=p^4+4p^2q+4pr+2q^2.$$

This law of recurrence extends to chain-fractions of all orders, and even to periodic continued fractions. Thus, in seeking the square root of 7 by the usual process, we get the successive quotients 2; 1, 1, 1, 4; 1, 1, 1, 4; &c., occurring in groups of four, and giving the converging fractions,

$$\frac{2}{1}\ \frac{1}{0},\ \frac{1}{2}\ \frac{1}{1},\ \frac{1}{3}\ \frac{1}{1},\ \frac{1}{5}\ \frac{1}{2},\ \frac{4}{8}\ \frac{4}{3};\ \frac{4}{37}\ \frac{1}{14},\ \frac{1}{45}\ \frac{1}{17},\ \frac{1}{82}\ \frac{1}{31},\ \frac{1}{127}\ \frac{1}{48};\ \frac{4}{590}\ \frac{1}{223},\ \frac{1}{717}\ \frac{1}{271},\ \frac{1}{1\,307}\ \frac{1}{494},\ \frac{1}{2\,024}\ \frac{1}{765},\ \&c.$$

If we select here the last term of each group as $\frac{1}{0}$, $\frac{8}{3}$, $\frac{127}{48}$, $\frac{2\,024}{765}$, &c., or the first term as $\frac{2}{1}$, $\frac{37}{14}$, $\frac{590}{223}$, &c., we form a progression with the multipliers $q=1$, $p=16$. Similarly, for the square root of 20, we get the quotients 4; 2, 8; 2, 8; &c., occurring in groups of two, the successive approximations being $\frac{4}{1}$; $\frac{9}{2}$; $\frac{76}{17}$, $\frac{161}{36}$; $\frac{1\,364}{305}$, $\frac{2\,889}{646}$, &c., in which the terms $\frac{1}{0}$, $\frac{9}{2}$, $\frac{161}{36}$, $\frac{2\,889}{646}$, &c., progress with the multipliers $q=-1$, $p=18$.

This circumstance greatly facilitates our investigations in quadratics; thus if the indeterminate equation

$$x^2=7y^2+1$$

were proposed, we have at once the solution by seeking $\sqrt{7}$, and taking the last term of each group; thus

$$\begin{aligned} x&= 8, & y&= 3,\\ x&= 127, & y&= 48,\\ x&=2024, & y&=1765, \text{ and so on.} \end{aligned}$$

are the solutions.

When the group of quotients consists of two terms α, β, the order of recurrence is given by $q=-1$, $p=\alpha\beta+2$.

For a period with the three quotients α, β, γ, we have $q=+1$, $p=\alpha\beta\gamma+\alpha+\beta+\gamma$.

For one with the four, α, β, γ, δ, we have $q=-1$, $p=\alpha\beta\gamma\delta+(\alpha+\gamma)(\beta+\delta)+2$.

The subject, however, is too extensive to be treated as an appendix to the present paper.

XIX.—*On Knots.* Part II. By Professor Tait. (Plate XLIV.)

(Read 2nd June 1884.)

One main object of the present brief paper is to take advantage of the results obtained by Kirkman,* and thus to extend my census of distinct forms to knottiness of the 8th and 9th orders; for the carrying out of which, by my own methods, I could not find time. But I employ the opportunity to give, in a more extended form than that in the short abstract in the *Proceedings*, some results connected with the general subject of knots, which were communicated to the Society on January 6, 1879, as well as others communicated at a later date, but not yet printed even in abstract.

I. *Census of* 8*-Fold and of* 9*-Fold Knottiness.*

1. The method devised and employed by Kirkman is undoubtedly much less laborious than the thoroughly exhaustive process (depending on the *Scheme*) which was fully described and illustrated in my former paper†; but it shares, with the *Partition* method, which I described in § 21 of that paper and to which it has some resemblance, the disadvantage of being to a greater or less extent tentative. Not that the rules laid down, either in Kirkman's method or in my partition method, leave any room for mere guessing, but that they are too complex to be always completely kept in view. Thus we cannot be absolutely certain that by means of such processes we have obtained all the essentially different forms which the definition we employ comprehends. This is proved by the fact that, by the partition method, I detected certain omissions in Kirkman's list, which in their turn enabled him to discover others, all of which have now been corrected. And, on this ground, the present census may still err in defect, though such an error is now perhaps not very probable.

On the other hand, the treatment to which I have subjected Kirkman's collection of forms, in order to group together all mere varieties or transformations of one special form, is undoubtedly still more tentative in its nature; and thus, though I have grouped together many widely different but equivalent forms, I cannot be *absolutely* certain that all those groups are essentially different one from another.

Unfortunately these sources of possible error, though they tend (numerically) in opposite directions, and might thus by chance compensate one another

* *Ante*, p. 281.

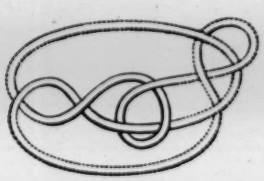
† On Knots, *Trans. R.S.E.*, 1876–7.

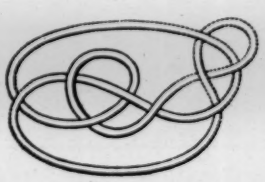
so far as to make the assigned numbers of essentially different forms accurate, cannot in any other sense compensate. In other words, there may still be some fundamental forms omitted, while others may be retained in more than one group of their possible transformations. Both difficulties grow at a fearfully rapid rate as we pass from one order of knottiness to the next above; and thus I have thought it well to make the most I could of the valuable materials placed before me; for the full study of 10-fold and 11-fold knottiness seems to be relegated to the somewhat distant future.

2. The problem which KIRKMAN has attacked may, from the point of view which I adopt, be thus stated:—"*Form all the essentially distinct polyehdra** (*whether solids, quasi-solids, or unsolids*) *which have three, four, &c., eight, or nine, four-edged solid angles.*" Thus, in his results, there is no fear of encountering two different projections of the same polyhedron; or, in the language of my former paper, no two of his results will give the same scheme. Thus there is no one which can be formed from another by the processes of § 5 of my former paper.

3. But, when a projection of a knot is viewed as a polyhedron, we necessarily lose sight of the changes which may be produced, by *twisting*, in the knot itself when formed of cord or wire; a process which (without introducing nugatory crossings) may alter, often in many ways, the character of the corresponding polyhedron. This subject was treated in §§ 4, 11, 14, &c., of my former paper. But it is so essential in the present application that it is necessary to say something more about it here. It would lead to great detail were I to discuss each example which has presented itself, especially in the 9-folds; but they can all be seen in Pl. XLIV., by comparing together two and two the various members of each of the groups.

The following example, however, though one only of several possible transformations is given, is sufficiently general to show the whole bearing of the remark, so far at least as we at present require it.





It is obvious that either figure may be converted into the other, by merely rotating through two right angles the part drawn in full lines, the dotted part of the cord being held fixed. Also, the numbers of corners or edges in the right and left handed meshes in these two figures are respectively as below:—

* This word is objectionable, on many grounds, in the present connection. But a more suitable one does not occur to me; and the qualification (given in brackets) will prevent any misconception. Of course no projection of a *true* polyhedron can be cut by a straight line in two points only.

55332	and	64332
443322		433332.

These numbers would necessarily be *identical* if the forms could be represented by the same scheme. As will be seen by the list below, § 6, these are respectively the second, and the sixth, of the group of equivalent forms of number VIII of the ninefold knots. (See Plate XLIV.)

The characters of the various faces of the representative polyhedra (so far at least as the number of their sides is concerned) are widely different in the two cases. [Mr KIRKMAN objects to this process that it introduces twisting of the cord or tape *itself*. No doubt it does, or at least seems to do so, but the algebraic sum of all the twists thus introduced is always zero; *i.e.*, by "ironing out" the tape in its new form, all this twist will be removed. I have often used a comparison very analogous to this, to give to students a notion of the nature of the kinematical explanation of the equal quantities of + and − electricity, which are always produced by electrification. If the two ends of a stretched rope, along whose cylindrical surface a generating line is drawn, be fixed, and torsion be applied to the middle by means of a marlinspike passed through it at right angles, one-half of the generating line becomes a right-handed, the other an equal left-handed cork-screw. Thus the algebraic sum of the distortions is zero. And, in consequence, if the rope be untwistable (the *Universal Flexure Joint* of § 109 of *Thomson and Tait's Natural Philosophy*) and endless, the turning of the spike merely gives it rotation like that of a vortex-ring. Such considerations are of weighty import in many modern physical theories.]

As will be seen, by an examination of the latter part of Plate XLIV., even among the forms of 9-fold knottiness there are several which are capable of more than one different changes of this kind. Some of these I may have failed to notice. But it is worthy of remark that the 8-folds seem, with two exceptions, to resemble the 7-folds in having at most two distinct polyhedral forms for any one knot.

4. KIRKMAN's results for knottiness 3, 4, 5, 6, 7, when bifilars and composites are excluded, agree exactly with those given in my former paper. I have figured these afresh in Plate XLIV., in the forms suggested by KIRKMAN's drawings, omitting only the single 6-fold, and the single 7-fold, which are composite knots.

As will be seen in the Plate, where they are figured in groups, there are but 18 simple forms of 8-fold knottiness. Besides these there are 3 not properly 8-fold, being composite (*i.e.*, made up of two *separate* knots on the same string); either two of the unique 4-fold, or a trefoil with one or other of the two 5-folds. These it was not thought necessary to figure, especially as they may present themselves in a variety of forms.

And the Plate also shows that there are 41 simple forms of 9-fold knottiness. Besides these, and not figured, there are 5 made up of two mere separate knots of lower orders, and one which is made up of three separate trefoils.

5. Thus the distinct forms of each order, from the 3rd to the 9th inclusive, are in number

1, 1, 2, 4, 8, 21, 47;

or, if we exclude combinations of separate knots,

1, 1, 2, 3, 7, 18, 41.

The later and larger of the numbers in these series, however, would be considerably increased if we were to take account of arrangements of sign at the crossings, other than the alternate over and under which has been tacitly assumed; and which are, in certain cases, compatible with non-degradation of the order of knottiness. This raises a question of considerable difficulty, upon which I do not enter at present. Applications to one of the 8-folds and to one of the 9-folds will be found in my former paper, § 42 (1).

Another interesting fact which appears from Plate XLIV. is, that there are six distinct amphicheiral forms of 8-fold knottiness: at least if we include one, not figured, which consists of two separate 4-folds; in which case we must consider that there are two six-fold amphicheirals, the second being the combination of right and left handed trefoils, described in § 13 of my former paper. Thus the number of amphicheirals is, in the 4-fold, 6-fold, and 8-fold knots respectively, either 1, 2, 6, or (if we exclude composites), 1, 1, 5. All but two of these 8-fold amphicheirals were treated in my former paper, two having been separately figured, and the other being a mere common case of the general forms of § 47.

Finally, as a curious addition to the paragraphs on the genesis of amphicheiral knots, given in my first paper, I mention the following, which is at once suggested by the amphicheiral 6-fold:—Keeping one end of a string fixed, make a loop on the other; pass the free end through it and across the fixed end; pass the free end again through the external loop last made, then across the fixed end, and so on indefinitely. The second time the fixed end is reached we have the trefoil (if the alternate over and under be adhered to), the third time we have the amphicheiral 6-fold; and, generally, the nth time, a knot of $3(n-1)$ fold knottiness, which is amphicheiral if n is odd. Three of these were, incidentally, given in my former paper.

But, reverting to the main object of my former paper, we now see that the distinctive forms of less than 10-fold knottiness are together more than sufficient (with their perversions, &c.) for the known elements, as on the Vortex Atom Theory.

6. From the point of view of theory, as suggested in §§ 12, 21, of my

former paper, it may be well to give here the partitions of $2n$ which correspond to true knots—for the values of n from 3 to 9 inclusive. The various partitions, subject to the proper conditions, are all given, in the order of the number of separate parts in each; those which have a share in one or more of the true knots, as given in the Plate, are printed in larger type.

$n=3$	$n=6$ (*contd.*)	$n=8$ (*contd.*)	$n=9$	$n=9$ (*contd.*)
33	42222	**772**	**99**	**66222**
222	**33222**	**763**	972	**65322**
	222222	**754**	963	**64422**
		664	954	**64332**
$n=4$	$n=7$	**655**	**882**	**63333**
		8422	873	**55422**
44	**77**	8332	**864**	**55332**
422	752	7522	855	**54432**
332	743	7432	774	**54333**
2222	**662**	7333	765	**44442**
	653	6622	**666**	**44433**
	644	**6532**	9522	822222
$n=5$	554	6442	9432	732222
	7322	**6433**	9333	642222
55	6422	**5542**	8622	633222
532	6332	5533	8532	**552222**
442	**5522**	**5443**	8442	**543222**
433	**5432**	4444	8433	**533322**
4222	**5333**	82222	**7722**	444222
3322	4442	73222	**7632**	**443322**
22222	**4433**	64222	**7542**	**433332**
	62222	63322	**7533**	**333333**
	53222	**55222**	**7443**	6222222
$n=6$	**44222**	**54322**	6642	5322222
	43322	**53332**	**6633**	**4422222**
66	**33332**	**44422**	**6552**	**4332222**
642	422222	**44332**	**6543**	**3333222**
633	**332222**	**43333**	6444	42222222
552	**2222222**	622222	**5553**	**33222222**
543		532222	**5544**	**222222222**
444	$n=8$	442222	93222	
6222		**433222**	84222	
5322	88	**333322**	83322	
4422	862	4222222	75222	
4332	853	**3322222**	74322	
3333	844	22222222	73332	

The whole numbers of available partitions are thus in order:—

2, 4, 7, 14, 23, 40, 66.

Of these there are employed for knots proper only

2, 1, 4, 4, 12, 17, 36,

respectively. The remainder give links, or composite knots, or combinations of these. (See *Appendix*.)

To enable the reader to identify, at a glance, any knot of less than 10-fold knottiness, I subjoin the partitions corresponding to each figure in Plate XLIV. It is to be remembered that (as in § 15 of my former paper) deformations which are compatible with the *same scheme*, however they may change the appearance

of a knot, do not alter the partitions. But it is also to be remembered that identity of partitions, alone, does not necessarily secure identity of form.

The 3, 4, 5, and 6-folds may be disposed of in a single line.

$n=3$	$n=4$	$n=5$		$n=6$		
33		442	55		543	552
222	$\overline{332}$	3322 ,	22222	$\overline{4332}$,	33222 ,	33222

Here the bar indicates not only that the right and left-handed partitions are alike in number and value, but also that they are similarly connected, *i.e.*, that the knot is amphicheiral.

For the Sevenfolds, we have

I.	II.	III.
5333 or 4433	5432 or 5432	5432 or 4433
43322 43322	43322 33332	44222 44222

IV.	V.	VI.	VII.
644	5522	662	77
332222	44222	332222	2222222

For the Eightfolds,

I.	II.	III.
	54322 or 54322 or 54322	53332 or 44332
$\overline{44332}$	53332 44332 43333	44422 44422

IV.	V.	VI.	VII.
5443	54322	6532 or 6532	
333322	44332 or $\overline{54322}$ or $\overline{44332}$	333322 433222	$\overline{43333}$

VIII.	IX.	X.	XI.
6433 or 5443	5542	54322 or 54322	55222 or 55222
433222 433222	433222	44332 54322	44332 54322

XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.
	6532	655	763	754		772
$\overline{54322}$	433222	3322222	3322222	3322222	$\overline{55222}$	3322222

Finally, for the Ninefolds, the list is

I.	II.
44433	63333 or 63333 or 54333 or 54333 or 44433 or 44433
433332	533322 443322 533322 443322 533322 443322

III.

$$\begin{matrix}54333\\443322\end{matrix} \text{ or } \begin{matrix}44433\\443322\end{matrix}$$

IV.

$$\begin{matrix}54432\\533322\end{matrix} \text{ or } \begin{matrix}54432\\533322\end{matrix} \text{ or } \begin{matrix}54432\\443322\end{matrix} \text{ or } \begin{matrix}54432\\443322\end{matrix}$$

V.

$$\begin{matrix}44442\\443322\end{matrix}$$

VI.

$$\begin{matrix}64332\\443322\end{matrix} \text{ or } \begin{matrix}55332\\443322\end{matrix} \text{ or } \begin{matrix}64332\\443322\end{matrix}$$

VII.

$$\begin{matrix}54432\\433332\end{matrix} \text{ or } \begin{matrix}54432\\433332\end{matrix}$$

VIII.

$$\begin{matrix}64332\\443322\end{matrix} \text{ or } \begin{matrix}55332\\443322\end{matrix} \text{ or } \begin{matrix}64332\\533322\end{matrix} \text{ or } \begin{matrix}55332\\533322\end{matrix} \text{ or } \begin{matrix}55332\\433332\end{matrix} \text{ or } \begin{matrix}64332\\433332\end{matrix}$$

IX.

$$\begin{matrix}54432\\443322\end{matrix}$$

X.

$$\begin{matrix}5553\\3333222\end{matrix}$$

XI.

$$\begin{matrix}5544\\3333222\end{matrix}$$

XII.

$$\begin{matrix}64422\\433332\end{matrix} \text{ or } \begin{matrix}64422\\333333\end{matrix} \text{ or } \begin{matrix}64422\\533322\end{matrix} \text{ or } \begin{matrix}64422\\443322\end{matrix}$$

XIII.

$$\begin{matrix}55422\\443322\end{matrix} \text{ or } \begin{matrix}55422\\533322\end{matrix} \text{ or } \begin{matrix}55422\\433332\end{matrix}$$

XIV.

$$\begin{matrix}65322\\433332\end{matrix} \text{ or } \begin{matrix}65322\\433332\end{matrix} \text{ or } \begin{matrix}65322\\533322\end{matrix} \text{ or } \begin{matrix}65322\\443322\end{matrix}$$

XV.

$$\begin{matrix}65322\\443322\end{matrix} \text{ or } \begin{matrix}55332\\443322\end{matrix} \text{ or } \begin{matrix}55332\\543222\end{matrix} \text{ or } \begin{matrix}65322\\543222\end{matrix}$$

XVI.

$$\begin{matrix}7632\\3333222\end{matrix} \text{ or } \begin{matrix}7632\\3333222\end{matrix} \text{ or } \begin{matrix}7632\\4332222\end{matrix}$$

XVII.

$$\begin{matrix}64332\\533322\end{matrix} \text{ or } \begin{matrix}64332\\443322\end{matrix} \text{ or } \begin{matrix}54432\\533322\end{matrix} \text{ or } \begin{matrix}54432\\443322\end{matrix}$$

XVIII.

$$\begin{matrix}64332\\543222\end{matrix} \text{ or } \begin{matrix}54333\\543222\end{matrix} \text{ or } \begin{matrix}54432\\543222\end{matrix}$$

XIX.

$$\begin{matrix}55422\\533322\end{matrix} \text{ or } \begin{matrix}55422\\443322\end{matrix}$$

XX.

$$\begin{matrix}55332\\543222\end{matrix} \text{ or } \begin{matrix}54432\\543222\end{matrix} \text{ or } \begin{matrix}54432\\543222\end{matrix}$$

XXI.

$$\begin{matrix}7443\\4332222\end{matrix} \text{ or } \begin{matrix}7443\\3333222\end{matrix} \text{ or } \begin{matrix}6543\\3333222\end{matrix} \text{ or } \begin{matrix}6543\\4332222\end{matrix}$$

XXII.

$$\begin{matrix}7533\\4332222\end{matrix} \text{ or } \begin{matrix}6633\\4332222\end{matrix} \text{ or } \begin{matrix}7533\\3333222\end{matrix} \text{ or } \begin{matrix}6633\\3333222\end{matrix}$$

XXIII.

$$\begin{matrix}6543\\4332222\end{matrix} \text{ or } \begin{matrix}5553\\4332222\end{matrix}$$

XXIV.

$$\begin{matrix}6552\\4332222\end{matrix} \text{ or } \begin{matrix}6552\\3333222\end{matrix}$$

XXV.

$$\begin{matrix}64422\\443322\end{matrix} \text{ or } \begin{matrix}44442\\543222\end{matrix} \text{ or } \begin{matrix}44442\\443322\end{matrix} \text{ or } \begin{matrix}64422\\543222\end{matrix}$$

XXVI.

$$\begin{matrix}66222\\443322\end{matrix} \text{ or } \begin{matrix}66222\\543222\end{matrix} \text{ or } \begin{matrix}66222\\443322\end{matrix}$$

XXVII.

$$\begin{matrix}5544\\4422222\end{matrix} \text{ or } \begin{matrix}6543\\4422222\end{matrix}$$

XXVIII.

$$\begin{matrix}7533\\4332222\end{matrix} \text{ or } \begin{matrix}6543\\4332222\end{matrix}$$

XXIX.

$$\begin{matrix}64422\\543222\end{matrix} \text{ or } \begin{matrix}64422\\443322\end{matrix}$$

XXX.

$$\begin{matrix}7542\\4332222\end{matrix} \text{ or } \begin{matrix}7542\\3333222\end{matrix}$$

XXXI.

$$\begin{matrix}65322\\543222\end{matrix} \text{ or } \begin{matrix}55332\\543222\end{matrix}$$

XXXII.		XXXIII.		XXXIV.		XXXV.
44442 / 552222	or 64422 / 552222	7632 / 4422222	or 6633 / 4422222	7542 / 4422222	or 5544 / 4422222	44433 / 333333

XXXVI.	XXXVII.	XXXVIII.	XXXIX.	XL.	XLI.
666 / 33222222	864 / 33222222	882 / 33222222	66222 / 552222	7722 / 4422222	99 / 222222222

It will be seen that the above list suggests many curious remarks. Thus, in the eightfolds, we have two *different* amphicheirals, each having the partitions $\overline{44332}$. Again, we have $\begin{matrix}54322\\54322\end{matrix}$ for a knot which is not amphicheiral, as well as $\overline{54322}$ for one which is amphicheiral. (See § 47 of my former paper.) And we have $\begin{matrix}54322\\44332\end{matrix}$ standing for two quite distinct knots. All these apparent difficulties, however, are due to the incompleteness of the definition by partitions *merely* (*i.e.*, as by LISTING's Type-Symbol). For, in addition to this, it is requisite that we should know the relative grouping of the right-handed or of the left-handed partitions.

In the Plate I have inserted the designations given in my former paper to the various forms of 6-fold and 7-fold knottiness:—and I have also appended to each form the designation of the corresponding figure in KIRKMAN's drawings.

The Plate contains a great deal of information of a kind not yet alluded to in this paper. It gives, for instance, an excellent set of examples of *Knotfulness*. This term implies (§ 35 of my former paper) "*the number of knots of lower orders* (*whether interlinked or not*) *of which a given knot is built up.*" It is to be understood as applied to *simple* forms only; for we have set aside, as *composite* knots, all such as have any one component separable, so that it may be drawn tight without fastening together two laps belonging to one or two of the other components.

Thus, as a few of the examples of 2-fold knotfulness among the 8-folds, we have

VI. and XI. (3-fold and once-beknotted 5-fold);

and II. and V. (each two 4-folds); while

III., IX., and XIV. are different forms of two (linked) 3-folds.

Among the 9-folds we have, for instance,

XXX. and XXXIII. (4-fold and clear-coiled 5-fold),

XVI. and XXVI. (3-fold and δ 6-fold),

XIV., XV., XVIII., and XXV. (4-fold and once-beknotted 5-fold).

But we have also

IV., XIII., XXIII., and XXIV. (linked 3-fold and 4-fold),

XX., XXVII. (two 3-folds, linked, and with one kink).

The analysis of self-locked knots, such as IV. and VII. of the 8-folds, and II., IX., X., XIX., &c., of the 9-folds, is considered below.

II. *Beknottedness.*

7. The question of *Beknottedness* (on which I have occasionally made short communications to the Society since my papers of 1876-7 were printed in a brief condensed form) has been again forcibly impressed on me while endeavouring to recognise identities among KIRKMAN's groups. I still consider that its proper measure is *the smallest number of changes of sign which will remove all knottiness.* But, shortly after my former paper was published, I was led to modify some ideas on the subject, which were at least partially given there. I had been so much impressed by the very singular fact of the existence of amphicheiral forms, that I fancied their properties might in great measure explain the inherent difficulties of this part of the subject. I have since come to see that this notion was to some extent based on an imperfect analogy, due to the properties of the 4-fold amphicheiral, and that the true difficulty is connected with *Locking.*

8. The existence and nature of this third method of entangling cords were first made clear to me by one of the random sketches which I drew to illustrate Sir W. THOMSON's paper on *Vortex-Motion* [*Trans. R. S. E.*, 1867–8]. I had not then even imagined that the crossings in any knot or linkage could *always* be taken alternately over and under, though I found that I could make them so in all these sketches. The particular figure above referred to again presented itself, among others possessing a similar character, while I was studying the peculiar group of plaited knots whose schemes contain the lettering n alphabetical order in the even as well as in the odd places. (See §§ 27, 42, of my former paper.) But I soon saw that, though I had first detected locking in those members of the group of plaits where *three* separate strings are involved, essentially the same sort of thing occurs in the other members of the group, though they are also proper knots in the sense of being each formed



with a *single* continuous and endless string. And, as the above very simple example sufficiently shows, we can have locking, independent of either knotting or linking, with *two* separate strings. For it is clear that the irreducibility

of this combination depends solely upon the sign of the *central* crossing. There is no real linking of the two cords, and there is obviously no knotting. But if the sign of any one of the crossings, except the central one, be changed, the whole becomes the simple amphicheiral link, the linking having been *introduced* by the change of sign. [This, as will be seen in § 14 below, is an excellent example of a case in which the key-crossing of a locking is also a root-crossing of a fundamental loop.]

9. We may therefore define, as one degree of locking, any arrangement, or independent part of an arrangement, analogous to that above (whether it be made of one, two, or three separate strings), the criterion being that the change of one sign unlocks the whole. But it is well to notice, again, that if, in the above figure, we change the sign of any crossing except the central one, we have one degree of linking left, and that this has in reality been *introduced* by the change of sign. This remark extends, with few exceptions, to more complex cases.

10. Thus, though the following 8-fold knot (which I reproduce from *Trans. R. S. E.*, 1877, p. 188) does not, at first sight, appear to depend on



locking, we have only to make a simple transformation (as *ante*, § 3) to reduce it to the symmetrical form in which the single degree of locking is



at once evident. It was by considering this knot, with its (quite unexpected) single degree of beknottedness, that I first saw the true bearing of locking in the present subject. (It is given as x. of the 8-folds in Plate XLIV.)

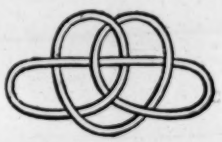
Other excellent instances of the same difficulty are the following. The first of these is completely resolved, the second changed to the 3-fold, while the third becomes apparently two linked trefoils, all by the change of the single crossing in the middle of the lock. But with the 9-fold knot (which is merely a different

projection of Pl. XLIV. fig. xxxv.) the trefoils are so linked after this operation, that the change of sign of one crossing of either resolves the whole.



This is, however, much more easily seen by at once changing the signs of the middle and of the lower (or the upper) crossing, for the whole is thus resolved. [This course is at once pointed out by the process of § 13 below, if we choose as *fundamental* crossings the three highest in the figure.] Hence the beknottedness is 1, 2, 2 in the last three figures respectively.

11. Another instructive example is afforded by the 8-fold knot below, which is figured as IV. on Plate XLIV. :—



At a first glance it appears to be made of two once-linked trefoils, and therefore to have three degrees of beknottedness. But a little consideration shows that neither the trefoils nor the link have alternations of signs (*i.e.*, there is neither knotting nor linking), but that the whole is kept from resolution solely by the lap of cord which has been drawn as a straight line in the figure. This forms, as it were, the tail of a Rupert's drop; break it, and the whole falls to pieces. A change of sign of either of the interior crossings on that lap *makes* one trefoil; of either of the 4 lateral external crossings, the 6-fold amphicheiral; of the upper crossing, the 4-fold amphicheiral; and of the lower axial crossing, the 5-fold of one degree of beknottedness. All these modes of resolution lead to the result that the knot is of 2-fold beknottedness.

12. It is now obvious why, in consequence of locking and not of amphicheiralism as I first thought, the electro-magnetic test fails in certain classes of cases to indicate properly the amount of beknottedness. For it is clear that in pure locking there is no electro-magnetic work along the locked part of any one of the three courses involved. Hence, for the part of a knot or link which is locked, the electro-magnetic test necessarily gives an incorrect indication of beknottedness. Perhaps it may be said that, in such cases, beknottedness is not the proper name for this numerical feature of a knot:—but it is obviously correct *if defined as in* § 7 *above.*

13. A simple but thoroughly practical improvement on the methods given in my first paper for the graphical solution of GAUSS' problem (extended) is as follows:—Draw the knot or link, as below, with a double line, like the edges of an untwisted tape, and dot (or go over with a coloured crayon) one of the



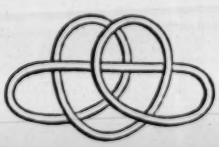


two lines. Now it is easy to see that, of the four angles at a crossing, one angle is bounded by full lines, and its vertical angle by dotted lines. These will be called the *symmetrical* angles. Also it is clear that the electro-magnetic work has one sign for the crossings when the symmetrical angles are right-handed, and the opposite sign when they are left-handed. Thus we can at once mark each crossing as *r* or *l*, silver or copper, at pleasure. If the figure be a knot, and if we cut it along a line dividing a symmetrical angle, re-uniting the pairs of ends on either side of that line, the whole remains a knot (still with alternations of over and under if the original was so), but of knottiness at least one degree lower. When the line divides an unsymmetrical angle, the whole becomes (after re-uniting the ends, as before) two separate closed curves, in general linked and, it may be, individually knotted. [When we treat a *link* in this way at any of the linkings (*i.e.*, where two *different* strings cross one another), it becomes a knot. It is curious that by this process a knot is equally likely to be changed into a knot or into a link, while a link *always* becomes a knot.] This method has the farther advantage of showing at a glance the various sets of crossings which we may choose for omission (in the electro-magnetic reckoning), as due merely to the *coiling* of the figure, not to knotting, linking, or locking. For each such crossing must belong to a simple loop, which, for reference, we will call *fundamental*. Such a loop is detected immediately by its having (throughout) the full line or the dotted line for its external boundary, and therefore is necessarily closed at a symmetrical angle. If we now erase these fundamental loops in succession, till no crossings are left, the crossings at their bases form one of the groups which may be tried. When part of the knot has locking, it is sometimes necessary to try more than one of these groups before we arrive at the true measure of beknottedness. As this is a matter of importance, it may be well to discuss it a little farther.

14. When there is no beknottedness (whether true, or depending on linking or locking), the electro-magnetic work, with the proper correction for mere coiling, is certainly *nil*. But this *proper* correction requires to be found, and where there is locking its discovery sometimes presents a little difficulty. When there is no locking, all we need do is to draw the knot afresh, beginning

at a point external to each of the fundamental loops, and making each crossing positive *when we first reach it.* It is evident that the fundamental loops or coils will now be simply laid on one another. The signs of *all* the crossings on any one loop may be changed, while that of the base of the loop is immaterial, and this process may be carried out with some or all of the other fundamental loops in any order. Compare the various signs in any state thus produced with those (alternate or not) of the original knot, so as to find the smallest number of changes necessary for its full resolution. The sign of the crossing at the base of each fundamental loop is simply to be disregarded. Another mode of going to work is to alter the signs at pairs of points where two fundamental loops cross, so as to diminish as far as possible the necessary number of real changes of sign. But we must be very careful in using this process, to see *that it does not introduce locking.*

15. When there is locking in part of the knot, the real difficulty is met with *only* if the crossing or crossings which form as it were the key of the locked part, *must* also be taken as the base or bases of fundamental loops. In this case we commence the fresh drawing of the knot at a point exterior to the locking, but on the fundamental loop of which one of the key crossings forms the base. This ensures that the completion of the fundamental loop is effected by the *last* of the operations on the locked part. But the application of the method can be learned far more easily from an example or two than from any rules which could be laid down. Thus the following drawings represent the results of this method as applied to two of the knots already figured. In the





first of these the two lower external crossings are taken for the fundamental loops, and we see that the knot (if originally over and under alternately) requires for its full resolution only the change of sign of each of the two crossings which lie in its axis of symmetry. But, if we had chosen the crossings last mentioned as bases of fundamental loops, we should at once have felt the difficulty due to locking.

In the second, all four crossings in the axis of symmetry close fundamental loops; but the change of the sign of the *lowest* of these, alone (which is the key of the locked part), is required for the full resolution.

APPENDIX.

Note on a Problem in Partitions. By Professor TAIT.

(Read July 7, 1884.)

In the partition method of constructing knots of any order, n, of knottiness, we have to select from the group of partitions of $2n$ those only in which no part is greater than n, and no part less than 2.

Thus, as given in the text, § 6, we have for sevenfold knottiness the series of partitions of 14;—but they are now arranged below in classes according to the value of the largest partition.

77	662	554	4442	33332	2222222
752	653	5522	4433	332222	
743	644	5432	44222		
7322	6422	5333	43322		
	6332	53222	422222		
	62222				

It is an interesting inquiry to find how many there are in each class, for any value of n. The number of classes is obviously $n-1$; and, if we remove from each the first partition (*i.e.*, that which is not inferior to any of the others), the remainders form a new set of classes of partitions which we may designate as

$$p_n^n, p_{n+1}^{n-1}, p_{n+2}^{n-2}, \ldots p_{2n-2}^2$$

respectively;—where p_s^r is defined as the number of partitions of s, in which no partition is greater than r, and none less than 2.

Without explicitly introducing finite differences or generating functions it is easy to calculate the values of the quantity p_s^r;—and to put them in a table of double entry which can be developed to any desired extent by the simplest arithmetical processes. The method is similar to one which I employed some years ago for the solution of a problem in Arrangements (*Proc. R.S.E.*, viii. 37, 1872).

In the first place we see at once that if $r > s$

$$p_s^r = p_s^s.$$

Thus, if r denote the column, and s the row, of the table in which p_s^r occurs, all numbers in the row following p_s^s are equal to it. Thus the values of p_s^s enable us to fill up half the table. In the remaining half r is less than s; and by a dissection of this class of partitions, similar to that which was given above, we see that

$$p_s^r = p_{s-r}^r + p_{s-r+1}^{r-1} + \ldots + p_{s-2}^2 + p_{s-1}^1 + p_s^0,$$

where the two last terms obviously vanish; and the first term is obviously 1 in the case of $r = s$, unless $r < 2$, when it vanishes.

Hence, if the following be a portion of the table, the crosses being placed for the various values of p^r_s, *nil* or not,

Values of s. \ Values of r.	0	1	2	3	4	5	6	7	8
0	+	+	+	+	+	+	+	H	+
1	+	+	+	+	+	+	G	+	+
2	+	+	+	+	+	F	+	+	+
3	+	+	+	+	E	+	+	+	+
4	+	+	+	D	+	+	+	+	+
5	+	+	C	+	+	+	+	+	+
6	+	B	+	+	+	+	+	+	+
7	A	+	+	+	K	+	+	L	L

it will be seen at a glance that the above equation tells us to add the numbers A, B, C, D, E together, to find the number at K. This is quite general, so that L, in the second last column, is the sum of A, B, ... , H; and all the numbers beyond it, in the same row, are equal to it. In the table on next page, each number corresponding to the *first* L is printed in heavier type, and its repetitions are taken for granted.

Thus it is clear that simple addition will enable us to construct the table, row by row, provided we know the numbers in the first row and those in the first column. Those in the first and second columns are all obviously zero, as above. The rest of the first row consists of units. These are the values of p^r_0, *i.e.*, the first term of the expression above for p^r_r. Hence we have the table on the following page, which is completed only to $r=17$, with the corresponding sub-groups.

From the table we see that $p^9_9 = 8$. Hence the partitions of 18, subject to the conditions, are in number

$$8+11+11+14+10+8+3+1=66,$$

which agrees with the detailed list in § 7 above.

[The rule is to look out the number p^n_n, and add it to all those which lie in the diagonal line drawn form it *downwards* towards the left. But the construction of the table shows us that this is the same as to look out p^n_{2n} at once.]

Similarly we verify the other numbers of partitions given in the text.

And it is to be remembered that p^n_n is the number of required partitions in which n occurs, and that *every one* of the class p^{n-r}_{n+r} has for its largest constituent $n-r$. Thus, looking in the table for p^7_7 and the numbers in the corresponding downward left-handed diagonal, we find the series

$$4 \quad 6 \quad 5 \quad 5 \quad 2 \quad 1,$$

which will be seen at once to represent the dissection of the partitions of 14 given above.

The investigation above was limited by the restriction, imposed by the theory of knots, that no partition should be less than 2. But it is obvious that the method of this note is applicable to partitions, whether unrestricted, or with other restrictions than that above. The only difficulty lies in the *bordering* of the table of double-entry. Thus, if we wish to include unit partitions, all we have to do is to put unit instead of zero at the place $r=1$, $s=0$, and develop as before. Or, what will come to the same thing, sum all the columns of the above table downwards from the top, and write each partial sum instead of the last quantity added, putting unit at every place in the second column.

Similarly, we may easily form the corresponding tables when it is required that the partitions shall be all even, or all odd.

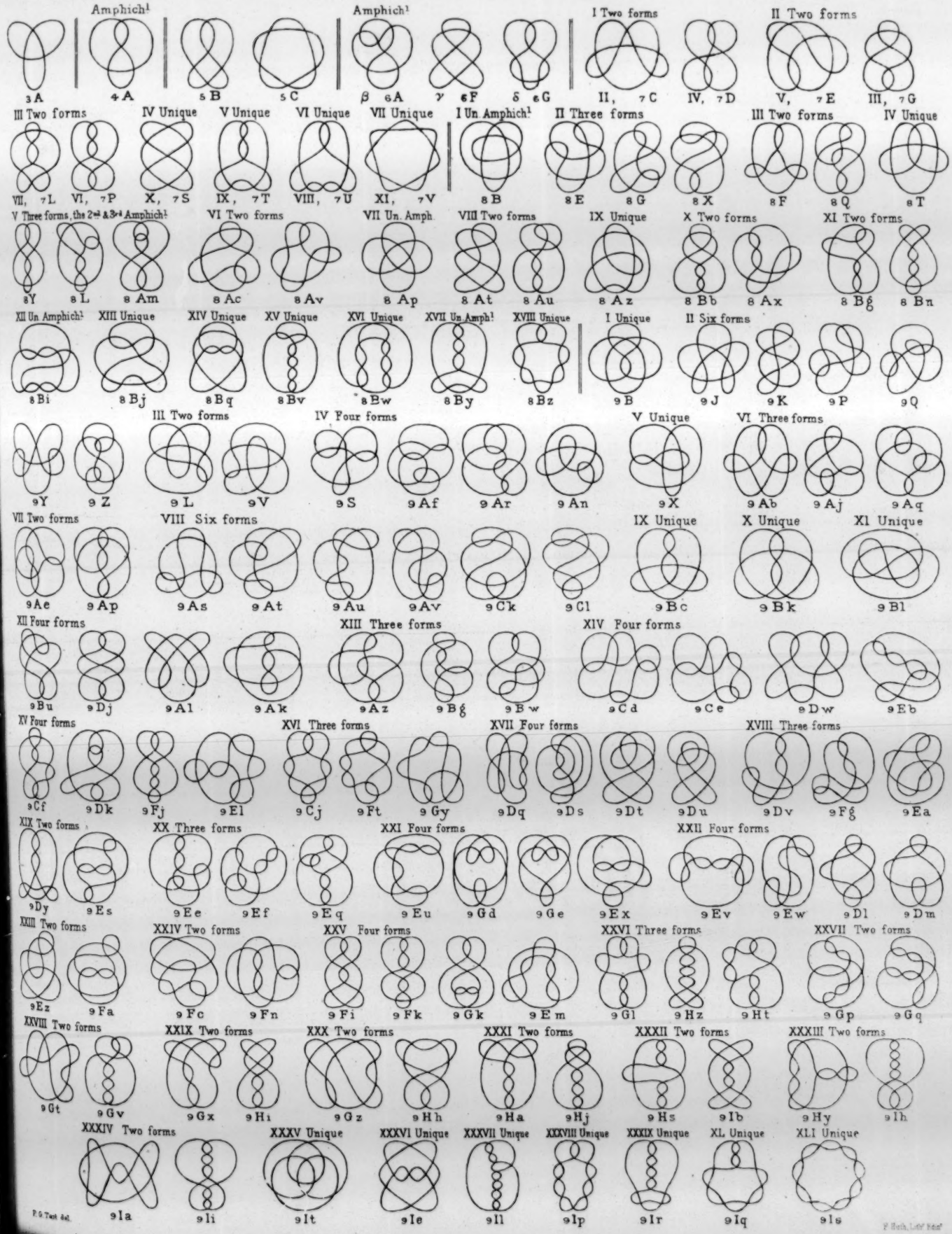
Table of the values of p_s^r; the number of partitions of s in which no one is less than 2, nor greater than r.

(*The values of* r *are in the first row, those of* s *in the first column.*)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0	0	0	**1**	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1	0	**0**	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
2	0	0	**1**	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
3	0	0	0	**1**	.	.	.	.	.	.	.	.	.	.	.	.	.	.
4	0	0	1	1	**2**	.	.	.	.	.	.	.	.	.	.	.	.	.
5	0	0	0	1	1	**2**	.	.	.	.	.	.	.	.	.	.	.	.
6	0	0	1	2	3	3	**4**	.	.	.	.	.	.	.	.	.	.	.
7	0	0	0	1	2	3	3	**4**	.	.	.	.	.	.	.	.	.	.
8	0	0	1	2	4	5	6	6	**7**	.	.	.	.	.	.	.	.	.
9	0	0	0	2	3	5	6	7	7	**8**	.	.	.	.	.	.	.	.
10	0	0	1	2	5	7	9	10	11	11	**12**	.	.	.	.	.	.	.
11	0	0	0	2	4	7	9	11	12	13	13	**14**	.	.	.	.	.	.
12	0	0	1	3	7	10	14	16	18	19	20	20	**21**	.	.	.	.	.
13	0	0	0	2	5	10	13	17	19	21	22	23	23	**24**	.	.	.	.
14	0	0	1	3	8	13	19	23	27	29	31	32	33	33	**34**	.	.	.
15	0	0	0	3	7	14	20	26	30	34	36	38	39	40	40	**41**	.	.
16	0	0	1	3	10	17	26	33	40	44	48	50	52	53	54	54	**55**	.
17	0	0	0	3	8	18	27	37	44	51	55	59	61	63	64	65	65	**66**
18	0	0	1	4	12	22	36	47	58	66	73	77	81	83	85	86	87	.
19	0	0	0	3	10	23	36	52	64	75	83	90	94	98	100	102	.	.
20	0	0	1	4	14	28	47	64	82	95	107	115	122	126	130	.	.	.
21	0	0	0	4	12	29	49	72	91	110	123	135	143	150	.	.	.	.
22	0	0	1	4	16	34	60	86	113	134	154	168	180	.	.	.	.	.
23	0	0	0	4	14	36	63	96	126	155	177	197	.	.	.	.	.	.
24	0	0	1	5	19	42	78	115	155	189	220	.	.	.	.	.	.	.
25	0	0	0	4	16	44	80	127	171	215	.	.	.	.	.	.	.	.
26	0	0	1	5	21	50	97	149	207	.	.	.	.	.	.	.	.	.
27	0	0	0	5	19	53	102	166	.	.	.	.	.	.	.	.	.	.
28	0	0	1	5	24	60	120	.	.	.	.	.	.	.	.	.	.	.
29	0	0	0	5	21	63	.	.	.	.	.	.	.	.	.	.	.	.
30	0	0	1	6	27	.	.	.	.	.	.	.	.	.	.	.	.	.
31	0	0	0	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.
32	0	0	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

From what has been stated in the previous pages, it is easy to see how to extend this table; forming the successive terms of each row by adding step by step upwards to the right along a diagonal, thence upwards to the top, zig-zag along the row of heavier type as soon as it is reached.

THE FIRST SEVEN ORDERS OF KNOTTINESS.



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XX.—*Philosophy of Language.* By Emeritus Professor J. S. Blackie.

(Read 7th April 1884.)

The Universe, as we have it, is an organised system of rational or reasonable forces and forms; of which the former are the product of the plastic, self-energising, productive power within, the latter the external presentation or manifestation of that power.

I. Language is a form of the fluid element, the air, moulded into shape by the vital forces of any living creature acting under the constraint of a determined organism, and significant of the sensations, emotions, sentiments, or thoughts of the creature; transmitted to and made appreciable to other similarly constituted creatures by the instrumentality of the ear, an organ nicely sensitive to all the affections of the fluid element, and thus naturally fitted to be the medium of intelligible communication between creature and creature in a system of social interdependence.

II. The simplest elements of language which we have in common with the lower animals are of the nature of cries ejaculated or instinctively sent forth from the vocal organs of the creature, under the stimulus of some sensations of pain or pleasure, either arising altogether from within, or called into action by some external agency, as the pricking of a pin,—such cries as the cawing of rooks, the purring of cats, the grunting of pigs, the braying of asses, the cackling of geese, the shrieking of women, and the roaring of men,—cries which arise necessarily from the nervous constitution and vocal organism of the creature, and which are naturally intelligible to all creatures of a kindred nature, and endowed with a responsive susceptibility. These cries in human language are, in the language of grammar, interjections: such as ha, ha! ho, ho! ὦ μοι, βαβαί. But they are in fact *verbs*, or at least the soul of a certain class of verbs, performing, as a means of communication between creature and creature, the complete function of verbs, and becoming perfect verbs in grammatical form directly they are tied down by certain modifications to definite relations of personality and time; of which anon.

III. Were a human being only a bundle of sensibilities, human language would consist merely of such ejaculatory words; but this sensibility is only the starting point of his existence, the point which he has in common with a mouse, a midge, or a monkey; he soon becomes a perceptive animal, and after that a mimetic or imitative animal; being moved by an unfailing instinct to reproduce, in some form or other, whatever striking forms or energising forces from without may

have strongly affected his nature. Hence, the whole family of words, in grammars stupidly called onomato-poetic, in which we recognise the germ of the dramatic element in literature, as in the ejaculatory element we may recognise the germ of the lyrical element. This whole class of words, representing originally all sorts of natural sounds, is manifestly the product of the native dramatic instinct of the human creature, and, though starting originally from impressions of sound, readily adapts itself by analogy to cognate impressions of the other senses, and even to emotions of the mind, and in this way claims a much larger domain in the field of every cultivated speech than would at first sight seem to belong to it.

IV. Our next proposition brings us to a higher and a characteristically human platform. When I call an ox, *bo—bor—baa*, as in Greek, Latin, and Gaelic, this, as a mere echo of an animal sound, might be repeated by a parrot, or any other animal with imitative instinct and apt vocal organisation. But the moment I use this imitative sound to express the name, not only of the individual animal which I just heard utter the sound, but the notion, idea, or type of a whole class of animals uttering the sound, I plant myself on a platform of intellect of which no animal, not even the cleverest monkey, is capable. The genesis of the idea in the human soul is a matter of which neither sensation nor sensibility can give any account; sensation is always the occasion, never the cause, of the idea. Four eggs, for instance, are no doubt felt to be four by a dog, or bull, or by a man; but the leap from that to the mathematical proposition, $2+2=4$, is infinite, and cannot be overbridged by any ingenuity. In forming the idea of an ox or a cow, the νοῦς or λόγος, which differentiates a man from a brute, acts plastically from its own dominant centre, and uses sensuous impressions merely as a multiform material on which the unity of an intelligent type is impressed; here we have the birth of human, that is intellectual language, a language expressive, not of sensations or of feelings, but of thoughts and ideas, which are as general as mathematical definitions, and are the pure creations of thinking. In forming them man acts as a god creating an organism; and this truth, so habitually ignored by a certain narrow school of physical scientists in these latter days, is not the least striking manifestation of the philosophic depth which lies at the bottom of that text—Gen. i. 27, "God made man in his own image." Here we see distinctly the reason why brutes have no language in the sense that we talk of human language. The vital forces which belong to them, being purely of sensational and emotional origin, are satisfied by the lowest form of vocal expression which we call cries; their language is in the main ejaculatory, and in some part also imitative. But there being no λόγος or νοῦς in them that craves for expressing in intelligible form, the words significant of types and general ideas, of course no such form appears; and man stands emphatically differentiated from them as the only

speaking, because the alone thinking animal; the λόγος of speech being in part only the outside of the λόγος of thought, and both expressed significantly in Greek by the same word. We say, therefore, distinctly that the mass of human language consists of an array of articulated sounds elevated by the power of self-acting imperial mind—βασιλικός νοῦς, as Plato calls it—from their original sensous significance into the region of thought, and made thus to serve as an organ of thinking in the communications of a specifically thinking animal.

V. That the νοῦς in the formation of language acts in its own imperial style, and not at all in the manner of LOCKE's unhappy simile of the sheet of blank paper, will appear plainly on considering the nature of that class of words which, in all languages, is found to express purely mental operations. They are, of course, formed by a secondary application of originally sensuous terms; but the point lies not in their origin, but in the selection made from a host of words of the same origin. Thus, in Greek—καταλαμβάνω, συνίημι, συλλογίζω; in Latin—*comprehendo, concipio, intelligo;* in German—*fassen, begreifen,* plainly imply a very distinctly energetic forthputting of the internal moulding faculty to lay hold of the material presented by the senses, as a potter lays hold of the clay. And in this regard it is not without interest to remark that, whereas verbs of sensation generally in Greek govern the genitive case, verbs of seeing, which is pre-eminently the intellectual sense, always govern the accusative; for the same reason evidently that active verbs generally govern that case, viz., because the accusative is a case of motion towards a point; that is the appropriate case to mark the invasion, so to speak, of the external material world, by the internal vital force of the observer in the act of cognition.

VI. The steps by which language grows from the original simple elements into the luxuriant expanse of significant sounds found in our dictionaries is not difficult to trace. The original stock, either in its single nakedness or with some modifications and slight additions, is adapted to new and very diverse uses by the law of similitude acting along with the law of parsimony. The law of parsimony, or a wise economy and a wise laziness, forbids to invent absolutely new words when old ones can serve the purpose; and the law of similitude, which the mind constantly follows in the classifications of science, as in the inspirations of poetry, by easy steps of transference, leads to an unlimited variety of uses of the same root, just as in the world of colour dark green may pass into light yellow. The changes of meaning which the root undergoes in this process of adaptation to new objects and new circumstances are always instructive and often amusing. We shall content ourselves with two familiar examples. The word *prick*, for instance, whether as a noun or a verb, is, I have no doubt, derived from the slight sharp sound made by a pin or a drop of rain

falling on a dry surface. The various forms which it has assumed in its passage through the millions of millions of human mouths during long centuries, from Sanscrit, through all the Teutonic languages, will be found in Skeat. They all signify a dot or spot, or the point that makes it, or the act of making it; and the last of the large progeny of small dots or points is one which is said to be produced either by native virtue of the academic soil at Oxford, or, as Lord REAY had it, by a peculiar metamorphosis which the rude unkempt Scot sometimes undergoes when he is transplanted to that atmosphere compounded curiously of the four elements of Greek, Episcopacy, Aristocracy, and Plutocracy; so that, to use the language of geologists, a *prig* is a metamorphic Scot, having in West End estimation the same relation to a normal Scot that a dainty Alderney cow has to a shaggy Highland stirk. This is the bright side of the creature, and the side of course from which he habitually contemplates himself. The dark side is revealed by the etymology which plainly sets him forth as a creature of small points and proprieties—a creature mighty in small matters—a sort of dainty drawing-room pedant—in whom the τὸ σεμνόν of true manhood has been altogether swallowed by the τὸ πρέπον of smooth convention, and the τὸ κομψὸν of petty elegance and superficial polish. Opposed to him is the *sumph*, a creature with neither points nor polish, from the German *sumpf*, a *bog*, σομφός, *porose*, a *boggy*-brained animal, whose depth, when he has any, is only a profundity of soft and sinking stupidity. Take now the word *bull*—not the animal which is kin to *Bo*, but the Pope's bull, which has nothing to do with the bovine cousinship in which the model Englishman glories. The Latin *bulla*, as every schoolboy knows, was a sort of boss or knob hung round the neck of patrician boys, and pet lambs sometimes, by fond Romish mamas; its original meaning was a bubble of water, from *bullio*, English *boil*. This round boss or knob, in a leaden avatar, came in the Middle Ages to be attached, as a sort of seal or stamp, to the thundering ordinances which his Holiness of the seven hills used to thunder over Europe largely, in order to crush kings and frighten fools; hence transferred to the document itself; and as the good old gentleman, with all his infallibility, sometimes blundered, a bull came to signify a blunder; and as Irishmen are famous for blunders, the little gilded ornament on the baby patrician's neck became metamorphosed into a blunder very closely akin to the bubble out of which the word arose.

VII. The modifications, in verbal form, which the root underwent, in order to adapt itself to new applications and to acquire new shades of meaning form two classes—those of which the origin and significance are either perfectly plain or can reasonably be presumed, and those of which the significance is altogether unknown, and in all probability not to be recovered. The general rule is, in the words of HORNE TOOKE: "Nothing in language is arbitrary or conventional." Language, like political constitutions and national character, is a growth,

not a convention or an institution. The most superficial dissection of the familiar forms of words, as we have them in our grammars, distinctly shows this. *Amo amas* means merely *love I, love thou;* the Sancrit *asmi*, the Latin *sum*, and the Greek εἰμί, being merely the two interflowing elements which are presented separately in the Gaelic *tha mi* and the English *I am*. So the case terminations in Greek and Latin are merely significant attachments expressive of local relationship which have grown into the root in these terminational languages, but of which the meaning stands clear in that detached form which these agglutinated postpositives present as independent propositions; the sign of the genitive in English *of* being manifestly = *off*, Greek ἀπό, Latin *ab*, *away from*. It matters nothing that we cannot in all cases, or in the majority of cases, distinctly put our fingers on the original significant form of the abbreviated or polished case termination; enough that man is a reasonable animal, and that from his reasonable proceeding in known cases we can certainly divine it in where the formative action is hidden from our view. Words as we have them, especially terminations, conjunctions, and other such frequently used and much abused elements of the vocal currency of a country, are like old shillings from which the image and superscription has been defaced, but which certainly was there, as it lies in the very nature of a coinage to bear some stamp and authoritative signature on its face.

VIII. That some modifications made in the root are without separate significance, and may without impropriety be called arbitrary and conventional, I think we must admit; and so HORNE TOOKE's rule, like other rules, will have its exceptions, and must not be pressed urgently in all cases. Any child could tell how *rubefacio* signifies to make red; it is merely two words run into one, in the same way that the Greek use ποιεῶ in ἀρτοποιός, a baker; but no man can tell me how *fell* came to signify to cause to fall, or how the plural of man should be men. No doubt in this latter case you may say that the *a* of the singular was changed into the *e* of the plural by the reflex contagion of the *e* in the plural termination *Männer;* but this is merely the description of a process of contagion or infection taking place between two contiguous emissions of articulated breath, not the laying bare of any natural significance in the change which has taken place. There is nothing in the word *fell* that should cause it to mean to cause to fall; it is a pure matter of convention—an ingenious device, let us say, to make one word serve two purposes, as faces have been made by ingenious draughtsmen representing two different persons, according as you look at them from this side or from that. In the same way no conceivable reason can be given why *wäre* in German, *were* in English, should be the subjunctive mood of *was*; or, what is similar, why the α of the indicative of the Sanscrit or Greek should be softened into η in the subjunctive. It is for the sake of variety and distinction alone that such changes are made; and they are in this view perfectly

analogous to the change of accent which takes place in English when a verb and a substantive are in all other respects identical, as in *prótest* and *protést*, or in the case of proper names in Greek—Διογενής, born of Jove; Διογένης, a man's name; δεξάμενος, having received; Δεξαμενός, Mr Receiver. A phenomenon somewhat different from these cases presents itself in the case of diminutives, which are made in most languages by the addition of terminations, which, though possessing no separate meaning in themselves, do really suggest the idea of littleness by the character of the differentiating syllables. Thus the terminal *l*, being a pleasant soft letter, and easy to dwell on prettily with a kindly tongue, seems to have been used in various languages to express diminutives—as in Latin *puer, puella, puerulus*; German *Magd, mädl*; Italian *donna, donzella, dama, damigella*. The same explanation may apply to the vowel ρ in the Greek παιδάρι, from παιδ. It is impossible, however, to see the same propriety in the termination ίσκος used to diminish substantives in Greek, as *ish* is to diminish adjectives in English, and *ike* in Scotch, as in *lass, lassie, lassikie*. It is probable that all these terminations, as also the Greek ικός adjectival termination, are only varieties of the verb ἐικω, to *be like*, in which case they belong not here, but to our previous section.

IX. Before proceeding further, it may be well to make two remarks about roots. (1) However remote the single Sanscrit monosyllabic roots in *dha, tha, ma*, &c., may appear from any ejaculatory or mimetic origin, I most firmly believe that they are merely the curtailed forms of words which had such an origin, starting from the impressions made on the senses or from external sensations; as, for instance, when MAX MÜLLER says that *pater*, a father, comes from the root *pa*, to nourish—even if that be true—I am not at all sure that the root *pa*, to nourish, did not first come from the kindly babble of infantile lips which produced *papa, mama, Amme*, μαῖα, and אַמָּא. (2) All roots are, and must have been verbs originally, for the simple reason that substantives could not receive names except from certain qualities residing in them; but qualities, so long as they are quiescent, do not strike the senses sufficiently to stir the soul to that vocal utterance which is the word; therefore adjectives, being quiescent qualities, could not be the first words, but verbs, which are energising qualities or functions. But the first word, though a verb, while the language-forming instinct is yet in its infancy, would answer all the three purposes of verb, substantive, and adjective; as happens in our bald and unterminational English every day—*fire, to fire, fireman*—which, had the Englishman spoken Greek, would infallibly have assumed the triple form of πῦρ, πυρέυω, and πυρευτής.

X. Hitherto we have spoken of language only as a useful machinery for the purpose of communication among social creatures; but language is also a fine art, and that in a double sense: a fine art fashioned by Nature under the influence of that striving towards the Beautiful which is apparent in all the

Divine workmanship, and again cultured and improved by man in virtue of his divine origin and divine mission on earth, so beautifully expressed by the Stoics—*Contemplari atque imitari mundum.* Now, in this view, the perfection of a language will depend in the first place, as in a musical instrument, on the number and variety and completeness of the notes which it contains, and again on the quality of these tones, and lastly on the skill with which they are used by a natural genius and a practised player. With this high ideal before us, we shall certainly find no human language perfect; for, besides that the organs of utterance in some cases may be of less perfect construction and of inferior capacity, the most highly gifted peoples in the use of language are apt to have pet tendencies and to fall into mannerisms, which are not only bad in themselves, but do an additional harm by excluding other less-favoured elements of a perfect vocal gamut from fair exercise. Thus the language becomes lopsided, and, as in the case of a body palsied in one limb, presents an appearance of completeness which its power of action does not warrant. It appears to have two arms, but can strike only with the right or with the left. Any vital function rarely used is used with difficulty, which gradually hardens itself into an impossibility; and so we find whole nations of the highest organic accomplishment unable to pronounce certain letters; as the Germans cannot pronounce *th* at all, and the English regularly change the χ of the Greeks and the Scotch *ch* into *k*. Some nations cannot even distinguish *r* and *l*, both liquids, no doubt, and so akin, but considerably different, both in the movement of the tongue by which they are pronounced, and in their musical effect on the ear. On the other hand, the aspirate which the German cannot enunciate is so familiar to the Celt that he introduces it regularly where it does not belong, and not rarely allows it, as in the Gaelic *ha* for *ta*, to override and delete the consonant which it modifies. There is hardly a nation that does not get into a bad habit of using one part of the machinery by which vocal breath is emitted with such preference as to impart a mannerism so strong as to become a distinctive mark of nationality; thus the Englishman, by the preferential use of the back of his mouth, gets into what is called the *ha-ha* style, and the curtailing of the *r* of its fair proportions, so that

I *saw*
A beautiful *sta-aw* = *star*,

is a perfectly good rhyme to a London, but not to an Edinburgh ear. The Greek, on the other hand, gave a preference to the front of the mouth, which produced the ψιλόν and the οὐ=oo, which the Englishman in his ignorant insular fashion refuses to recognise. The Yankee nasalism is another familiar instance of the same kind; and the vocalisation even of the liquid *l*, as in *Versailles*, of the modern French, is the most recent instance of the

polished feebleness in which that emasculated offspring of the Latin language delights.

XI. The quality of the vowels, and the choice and combination of consonants by which the music of language is specially affected, must depend partly on the delicacy of the original senses and organic tissue; and that this is influenced in a considerable degree by the climate, that is, by the atmosphere which the speaker breathes from his cradle, can scarcely be doubted. Hence the greater fulness and sweetness of the English vocalisation compared with the Scotch; hence, perhaps, the less musical character of the Teutonic languages generally as compared with the Greek and Latin. But, though climate no doubt asserts its sway here, as in a matter as much physical as moral, national character, at the same time, as the moral element which affects enunciation, cannot fail to make itself felt; so the Germans and the Scotch, being a more emotional people than the English, put more soul into their syllables, and draw out their words with a more kindly moral emphasis; and it seems impossible not to deduce the *nos tamen sumus fortiores* of Quinctilian, spoken in contrasting Latin with Greek, from the radically different character of the two peoples. But here we must remark, that the ideal of harmony in a language consists not merely in richness and sweetness, but in that grand and curiously varied combination of strength and sweetness by which the great compositions of a BEETHOVEN or a HANDEL distinguish themselves from a pleasant or a plaintive popular ditty. Now the strength or the bones of a language are in the consonants; and the trunk, so to speak, of the word lies in the root; so that the typical language is that which has always at hand a strong combination of consonants to express strong feelings, and a rich flow of vowels to express the more delicate emotions. Now, as we have already said, it is extremely difficult for a language to possess all excellences; as the French *avez* for *habetis*, *pêre* for the Italian *padre*, *peut* for *potest*, not to mention the systematic deletion of the *nt* in the final syllable of the present indicative of verbs, are a strong proof of how apt polish in this region is to degenerate into feebleness. Nay, it seems absolutely impossible, even in the best constituted languages, to combine sweetness with strength in the degree which an ideal type would demand; for, as the most significant and dramatically most effective part of a word lies in the root, it follows that whenever a strong utterance is to be fairly given, then the root which dramatically expresses the strong word ought to be made prominent. On the other hand, as the music of a language depends very much upon the cadence of the terminations, which in fact have only their vocalic element to recommend them, it follows that, whenever sweetness is to be expressed, these terminations ought not to be cheated of their natural emphasis. But, as a matter of fact, these terminations being affixed without distinction to all kind of roots, either, being accented, will swamp the root, or, being unaccented, will be apt to lose

part of their full musical value, or, at all events, prevent the root from standing so emphatically on its own legs, and producing its full dramatic effect. One line from HOMER will show this—

δούπησεν δὲ πεσών ἀραβῆσε δε τεύχε' ἐπ αὐτῳ,

and this may stand to verify the general proposition that the English language, besides being superior generally to either Greek or Latin in the dramatic truth and vigour of its roots, by virtue of its very lack of terminations, has a dramatic power in its daily use, which it is as impossible for Greek to emulate as it is impossible for English to emulate Greek in the volume of sentences and the cadence of periods.

XII. In the music of language, as the vowels are more sonant than the consonants, so the long vowels and the broad vowels, as *a* and *o* and *u*, are more musical than the short vowels and the slender vowels. Next to the quantity or volume of sound, the pitch of sound, accompanied as it naturally is with an emphatic dominance of the accented syllable, has a notable effect on the music of spoken address, and cannot be transposed or neglected without doing violence to the genius of the language. In respect of accent, the Greek, as noted by the ancient rhetoricians, has a decided advantage over the Latin, in allowing the accent to ride freely, according to certain laws, over the three last syllables; while the Latin, like the Gaelic, altogether excluded the accent from the last syllable of the word, where it is most musical. As the accent is one of the most characteristic, so it is one of the most persistent elements of the vocal life of a people; and in the case of Greek is, accordingly, prominent alike in the books of the ancient grammarian and in the mouths of the modern people; a fact which renders inexcusable the practice of English Hellenists in transferring wholesale the Roman system of accentuation to the Greek. We have no more right to tamper with the music of any language than with the colouring of a great painter or the diction of a great poet.

XIII. A written alphabet, or a body of visible signs significant of sounds, is no doubt a grand invention, and a great convenience, but belongs to the philosophy of language only in a very indirect fashion. A written, graven, or printed language is for record primarily, not for expression; like a photograph, it is an exact likeness, but without the expression which is the soul of the living image. An ORPHEUS, therefore, and a HOMER, the highest form of lyrical and epic poetry, was possible to Greece, if not before a written alphabet was known, certainly before it was used for purposes of writing and reading. Nevertheless, it seems certain that without the habit of writing and reading books, certain forms of literature which appeal to calm introspection, rather than to present excitement, could not have existed; without a written alphabet, HOMER

and HESIOD could never have been followed in due season by the large range of historical survey in HERODOTUS, and the condensed summation of political wisdom in THUCYDIDES. A printed alphabet, therefore, we may say, is the mother of prose literature, and of the wide expansion of intellectual sympathy and linguistic expression which a prose literature implies. A people that does not read and write will never demand and never acquire any form of intelligent utterance beyond the historical ballad, enlarged, it may be, into the popular epic, the sacred hymn, the secular song, and the popular harangue. An example of this we have at our own door in the Highlands. The only other remark that occurs to me to make on the alphabet is, whether it ought to be a system of visible symbols distinctly representing articulate sounds, as in all the languages with which European civilisation is familiar, or indirectly by means of abbreviated pictures of the things which the words represent, as in the ideographic writing of the Chinese. This method, compared with the other, is evidently the product of an earlier stage of civilisation, crude, clumsy, and cumbrous, having neither the poetry of a picture, nor the flexibility of an alphabet of spoken signs to recommend it. But whether the use of it entails on the people who have not advanced beyond this first stage of visible speech, any other disadvantage than the necessity of cumbering the mind with a more complex array of memorial signs, I do not know, and shall be happy to learn.*

XIV. Language, as noted above, is not a convention, but a growth; and as a growth, like the human individual, has its infancy, its youth, its manhood, its age, its decrepitude, and its death; and the same circumstances that favour or stunt the growth of the individual affect in a similar way the growth of a language. The best parentage for a language is a fine climate and a great story teller, in its infancy and youth. The Greeks had both. HOMER was at once their secular and their sacred Bible; and as such acted powerfully from the first, and without any diminution of action even to the present hour, both as a spur and a rein; a spur to exertion so brilliantly begun, and a rein to unregulated, unchastened, and unfraternising exertions in future fields of intellectual glory. The next condition of the luxuriant growth of language—of course, always supposing rich natural endowments—is that the national mind, the outcome of the national life, should not be disturbed in the natural progress of its evolution. This disturbance usually occurs from some extraneous influence, acting either violently in the way of conquest, or peacefully in the voluntary submission which a weak nation is always apt to pay to a stronger. From both these disturbing forces the Greek language remained free. Escaping triumphantly by the heroic struggles of Marathon and Salamis from the threatened

* Since this paper was read I have seen Professor LEGGE of Cambridge, who expressed himself decidedly of opinion that the ideographic writing of the Chinese acts as a hindrance to the rich development of the spoken language.

despotism of Asia over Europe, Greece had full time to put forth her intellectual strength in all departments, according to the law of a natural growth, before, from internal dissensions, she was obliged to submit politically to the world-wide influence of Rome. But here again the importance of an early and ripe culture of the national language showed itself in the most brilliant style. The conqueror, instead of crushing, stooped to adopt the language of the conquered; and when the Western Empire fell to pieces by the incursion of northern barbarians, Greek still flourished in the oldest half of the Christian Church and the Eastern half of the Roman Empire. It thus obtained a lease of life more than 1000 years beyond what might have been supposed to be the epoch of its natural demise; and when, by the overthrow of the Byzantine Empire in 1453, its complete collapse seemed almost certain, the repulsion between the Turkish faith and the Christian preserved the language from the amalgamating and absorbing force which, under the common circumstances of conquest, must have worked its dissolution. It remains, therefore, at the present hour, a wonder of linguistic longevity unique in the history of language, and bidding fair, in spite of the artificial life in which Latin is preserved by the Roman Church, to spread out the branches of a green old age over every part of the world that is not too wise in its own conceit, or too isolated in its own narrowness, to own the civilising influence of the moral culture which belongs to the present, only when it bears with it the most valuable inheritance of the past.

XV. The disturbing forces alluded to in the previous section either produce what may be called a violent death, if the resisting forces, as in the case of Gaul and Spain when conquered by Rome, are weak, or they produce a fusion more or less complete between the superimposed and the underlying stratum, and a mixed language of greater or less heterogeneousness of structure is produced. Such is the character of our own English tongue. Now, though it is quite sure that chance cannot make a language any more than a world, yet out of a chanceful throwing together of two languages, a mixed product of very excellent character may procced; just as when two good puddings are thrown together, the compound result will at all events contain all the good that is in each of the constituents, a good resulting not from the chance fashion of the mixture, but from the cunning preparation of the materials out of which the mixture was made. With all this, however, it is quite certain that this blind way of throwing two good puddings into one is not the way to make the best pudding; there is no certainty in such a process that the two puddings may harmonise and coalesce into a congruous, classical unity of the pudding genus. And so the English language, however excellent, and however worthy of the commendation of such a distinguished philologer as JACOB GRIMM, and however glorified by its having been made the organ of expression by the greatest dramatist the world ever saw, has some very manifest defects, which, both from a philological and a practical point

of view, place it on a lower platform than such self-developed languages as Greek and German. For (1) by the violent disturbance of its growth at an early period of its development, its power of compounding simple words and using its own roots has been so maimed and curtailed, that it is constantly obliged to borrow from all sources, in a fashion often clumsy and inelegant, and without that complete assimilation which is necessary to enable borrowed forms to satisfy the demands of a cultivated linguistic taste. (2) The linguistic instinct of the people acts so weakly that any irregularity creeps easily into it, and a subjection to the whims of fashion, that mar its æsthetic effect, and render it very difficult for a stranger to follow its vagaries. This remark applies particularly to the pronunciation and accentuation of our tongue. (3) What is worst of all, the immense mass of borrowed materials, taken and constantly being taken into our language from foreign sources, distinct both in space and time from our colloquial currency, issues in the creation of a stratum of language, running parallel to the vulgar English, which only scholars and persons of large foreign culture can readily understand; thus planting a prickly fence between the learned and the unlearned, in the highest degree unfavourable to the diffusion of scientific knowledge. It is an evil similar in kind, though less in degree, to that under which the whole of Europe suffered before the appearance of DANTE in Italy, SHAKESPEARE in England, and LESSING in Germany, viz., that, while social intercourse was carried on in the language of the country, knowledge of every kind was acquired and accumulated and stored in the language of the ancient Romans.

XVI. But the phenomena caused by the violent invasion of one language by another are not exhausted either by the complete extinction of the invaded language on the one hand, or by its hybrid mixture with the invading language on the other. It is possible, on the one side, that the language of the invaders, though maintaining its acquired dominion, and remaining in all its constituent elements substantially the same, may, through the combined effects of time, change of atmosphere, and action of new circumstances, undergo such extensive modifications as to become, not a new language indeed to the eye of the philologer, but an old language with a new face; and, on the other side, it is equally possible that the language of the invaded country, partly from its own inherited strength, partly from the intellectual weakness of the invader, may maintain its ground firmly, and yet, as in the previous case, from the influence of time and action of new social forces, become practically to the vulgar eye a new language, while to the scientific eye it is only a modification of the old. Of these two classes of what we may call, not mixed but metamorphic languages, the Romanesque languages—French, Spanish, Portuguese, and Italian—form familiar examples. To understand their formation we must bear in mind that, as all things in the world, specially all living things, in HERACLITUS' phrase, *ῥει πάντα*, are in a constant flux, so specially language, from being a very fluid material, and easily

yielding to slight and accidental influences, when it has once acquired a fixed and what may be called a classical type, can preserve this type only so long as the continuity of political and intellectual forces to which it and the type belong is not broken. The moment this continuity is broken, which acts as a restraining and conservative authority, the loose elements of which every language is composed are set adrift, so to speak, and left to be affected in every possible way by incalculable and often capricious forces, of which action, continued through generations, a metamorphic type of the original tongue must necessarily be the outcome. The changes thus produced on the old classical type of the language may be classed partly under the head of what MAX MÜLLER calls phonetic decay; that is, a smoothing and rubbing down of the language, by a process similar to attrition in the mineralogical world—a process which is always in one sense a corruption, and which often arises from no nobler cause than the laziness or carelessness of the speaker, but which, in the result, according to the degree of its action and the character of the materials acted on, may either be an emasculated enfeeblement or a musical improvement of the original tongue. But these changes are not all processes of decay; along with the decay a process of reconstruction is largely going on, in which the most active element is the coming to the surface and emphatic self-assertion of certain original vital and plastic forces in the popular tongue, which had been over-ridden and suppressed so long as authority and fashion maintained the cultivated type of the language in a position of acknowledged superiority. Add to these elements a very slight sprinkling of strange elements in the metamorphic tongue—such as of Arabic in Spanish, of Teutonic in French and Italian—and we have distinctly before us the conditions under which all metamorphic languages of the two classes represented by French and Italian assume their new type. Both languages are substantially Latin; but in the one the invading element became subject to the metamorphic action from the downfall of the Roman Empire, and the loss of all linguistic guidance thereon consequent; while in the latter the language of the invaded survived in a metamorphic shape, partly from the partial and irregular action of the invading powers, but principally from the ecclesiastical and intellectual supremacy which, under the most unfavourable circumstances, the invaded language did not fail to assert. It need scarcely be remarked also that, in proportion as the native Latin form of the language acted with more potency and with less disturbance on its native Italian ground than when transferred to Celtic France, in the same proportion, Italian would be a less corrupted, a more masculine, and a more majestic form of the old Roman tongue than that which is now wielded so dexterously by the brilliant wits and clever writers of the old insula Parisiorum.

XVII. Under this section, which has led me to talk of phonetic decay, I may put a question which has often occurred to me, but to which I felt I had no

materials for supplying a satisfactory answer, viz., whether is the extremely vocalic structure, and the weakness of the consonantal element observable in the language of certain savage or semi-savage peoples, owing to the attrition of time, or to an original defect in the lingual organisation of the race? Analogy leads to the former alternative; but both answers are possible; and local record alone, in the form of old inscriptions, or translations by missionaries in early times, could supply materials for deciding definitely on one side rather than on the other.

XVIII. The peaceful disturbance of the national process of growth, in any language, by the process of quiet decay and obliteration, takes place when a small people with an inferior literature finds itself in close geographical conjunction and in overpowering social connection with a people vastly superior in number, in wealth, in intelligence, in policy, and in every element that constitutes a highly developed social organism. In this case the language is doomed to a slow, it may be, but to a certain death; for as certainly as coals will be imported from Newcastle or Fife or Mid-Lothian by those who have none in Ross-shire or Caithness, so certainly will English ideas and English speech penetrate into the remotest glens of the Celtic Highlands; and though, as in Ireland, from obvious causes, the people may assert a distinct and well-marked nationality, the language in which their most cherished traditions have been handed down will not be able to maintain its ground. Not that there is anything desirable in the extinction of an old and venerable form of speech; quite the contrary. Let dying languages be preserved with pious care by those who love them, and those to whom they belong; there is no reason why we should kick our grandmother into her grave merely because she is old; let her tell her old stories and sing her old songs, nothing could be better—better even than sermons sometimes; but however good they may be, they can serve only for our occasional recreation, not for our daily food. The Celtic languages in Europe, with the miraculous facility of communication now everywhere to be found, will certainly die out in a very few generations; first in Ireland, strangely, where the Celtic blood is most hot; second, in the Scottish Highlands; and, lastly, in Wales. The Scottish language, again, though daily dying out, even among the lowest classes, as a medium of social intercourse, has a better chance of surviving, in its lyrical Avatar, as the Doric dialect of the English, if only the Scottish people would be true to themselves, and not submit so tamely to the process of Anglification which, from obvious causes, is spreading so rapidly over the land. A very little decent attention to the national music in our highest as well as in our lowest schools would act powerfully in preserving in a green old age the most pleasant manifestation of our existence as a separate people; but the mass of men in all countries are lazy and cowardly—οἱ πολλοὶ κακοὶ—and incline always to swim with the current rather than to ask whither

the current is driving them; and in a town like Edinburgh, which, though metropolitan by public law and by historical tradition, must, since the Union, be more or less provincial in respect of London, there will always be in influential quarters a considerable majority of persons who, under the influence of aristocracy, plutocracy, bureaucracy, and other potent forces working from above, will prefer the meretricious glitter of borrowed accomplishments to the healthy glow of home-grown virtues.

XXI.—*The Old Red Sandstone Volcanic Rocks of Shetland.* By B. N. Peach and J. Horne, of the Geological Survey of Scotland. (Plates XLV. and XLVI.)

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Perhaps the most interesting feature connected with the Old Red Sandstone formation in Shetland is the evidence of prolonged volcanic activity in those northern isles. The great development of contemporaneous and intrusive igneous rocks, which gives rise to some of the most striking scenery in Shetland, is all the more important when compared with the meagre records in the Lower Old Red Sandstone of Orkney and the Moray Firth basin. Not till we pass to the south of the Grampians do we find evidence of a far grander display of volcanic action during this period, in the sheets of lava and tuff in the Sidlaws and Ochils and in the great belt stretching from the Pentlands south-westwards into Ayrshire. The relations of the Shetland igneous rocks are admirably displayed in the various coast sections, especially in the mural cliffs of Northmavine and some of the Western Islands. From these records, though they have been subjected to much denudation, it is possible to construct a tolerably complete sketch of the volcanic history of this formation, as developed in that region.

No previous attempt has been made to furnish a chronological account of the Old Red volcanic phenomena of those northern isles. In HIBBERT's admirable volume * there are various references to the granite masses of the Mainland and the amygdaloidal claystones in the south-west of Northmavine. He also refers to the porphyritic and amygdaloidal rocks in Papa Stour, which were likewise described by Dr FLEMING.† In various papers published in the *Mineralogical Magazine*,‡ Dr HEDDLE notes the existence of interbedded and intrusive igneous rocks of this age in Shetland, with descriptions of the minerals obtained from them. The first attempt, however, to connect these Old Red volcanic rocks with their representatives south of the Grampians, was made by Dr ARCHIBALD GEIKIE, the present Director-General of the Geological Surveys. In 1876 the geological structure of Papa Stour, which is almost wholly composed of volcanic rocks, was solved by him in company with Mr B. N. PEACH; and, as the result of that traverse, an account of the geology of that interesting island was given in his celebrated paper on "The Old Red Sandstone of Western Europe," published in the *Transactions* of this Society.§ Though unable to visit the volcanic rocks on the north side of St Magnus Bay, he ventured to suggest that the amygdaloidal claystones referred to by HIBBERT would turn out to be merely a repetition of those in Papa Stour,—a suggestion which has been amply verified by subsequent investigations.

During our successive visits to Shetland, which were undertaken mainly with the view of examining the glacial phenomena of the group, we were induced to pay close attention to the distribution and geological structure of the Old Red Sandstone rocks, on account of the important bearing which they have on the ice-carry during the glacial period. A brief sketch of the development of the contemporaneous and intrusive igneous rocks was given in the paper which we communicated to the Geological Society in 1879.‖ But since that paper was read we have twice visited the islands in the course of our holiday rambles, in order to work out in greater detail the volcanic history of that period. Our last visit was specially devoted to the investigation of an interesting series of rhyolites, which have not hitherto been described, though at certain localities they have a remarkable development. A large number of microscopic sections have been prepared and examined, while detailed chemical analyses of the typical volcanic rocks have been made for us by our friend Mr R. R. TATLOCK, F.R.S.E., one of the public analysts for Glasgow. We now propose to lay the results of these investigations before the Society.

* HIBBERT's *Shetland Isles*, pp. 341, 474, 484, 491.
† *Mem. Wernerian Soc.*, vol i. p. 162.
‡ *Mineralog. Mag.*, vol. ii. pp. 160, 170 *et seq.*, 253; vol. iii. p. 32.
§ *Trans. Edin. Roy. Soc.*, vol. xxviii. p. 345.
‖ *Quart. Jour. Geol. Soc.*, vol. xxxv. p. 786.

I. Geological Structure of the Volcanic Rocks.

The records of volcanic activity are mainly confined to the west and north-west portions of the Mainland and the islands adjoining the western seaboard. They may be grouped in two divisions,—first, the contemporaneous igneous rocks, comprising the lavas and tuffs which were erupted and spread over the sea-floor during the accumulation of the sedimentary deposits; second, the intrusive igneous rocks, which were injected at a later date, probably towards the close of the Old Red Sandstone period in Shetland. The result of the chemical analysis of typical examples of these divisions clearly proves that the former belongs wholly to the basic series, while the latter includes both acidic and basic rocks.

A. *Contemporaneous Lavas and Tuffs.*

Beginning first with the interbedded volcanic rocks, the best development of them is to be found in the south-west part of Northmavine, between Stenness and the mouth of Rooeness Voe. No finer sections could be desired than those exposed along the storm-swept cliffs of the Grind of the Navir. Here and there the observer sees narrow "gios" which have been excavated in the tough lavas and ashes and occasionally a subterranean passage or tunnel, communicating with the surface by a funnel-shaped aperture, from which, during storms, a column of spray issues with the advancing tide. The best examples of this latter phenomenon are to be seen at the "Holes of Scraada."

The tract of ground occupied with this series of ancient lavas and tuffs measures about six miles in length from Stenness to Ockren Head. It is evident, however, that they must originally have covered a larger area, from the isolated fragments which have escaped denudation, in the islet of Doorholm, and Esha Ness Skerry. In the southern part of this tract, between Stenness and Hamna Voe, the terrace-shaped features which are characteristic of volcanic areas are so apparent, that the eye can easily follow the successive outcrops of the lavas and tuffs. This area is almost entirely occupied with contemporaneous volcanic rocks, there being but few intercalations of sedimentary deposits. Along the east side, between Rooeness Voe and Brei Wick, the lavas and tuffs are bounded by a great sheet of granite and quartz-felsite, which will be described in a subsequent page. On the south bank of Rooeness Voe, rather more than a mile from Ockren Head, the relation between the two is admirably exposed in a steep grassy "gyo." At this locality the slaggy porphyrites, which form a cliff about 300 feet high, with a beautifully slicken-sided surface, are brought into conjunction with the pink granitoid rock by a fault. Owing to the covering of peat, we were unable to trace this fault across the

peninsular tract. On the shores of St Magnus Bay at Brei Wick, the interbedded and intrusive igneous rocks are not found in such close proximity; the junction between the two being concealed by a sandy beach. From the admirable coast sections there is little difficulty in determining the geological structure of the volcanic masses. They form a great syncline, the centre of which is occupied by a coarse volcanic breccia or tuff and from underneath this breccia there crops out a series of slaggy diabase-porphyrites, with occasional beds of red ashy sandstones and flags. Such is the general arrangement of the strata, though the succession is occasionally disturbed by faults of greater or less magnitude. The order of succession is best displayed in the cliffs bounding St Magnus Bay, and we shall therefore describe first of all the section between Brei Wick and Stenness. On the west side of Brei Wick Bay, which is the eastern limit of the interbedded volcanic rocks, the following section is visible.



FIG. 1.—Section in Brei Wick Bay, Northmavine.

At the east end of this section occurs a bed of coarse tuff (2), with bombs of porphyrite, averaging 6 inches across, which is succeeded by finer tuff (1); the strata forming a small synclinal fold. Towards the west they are underlaid by red sandstones (3), which are pierced by a mass of pink quartz-felsite (4), like the intrusive igneous rock to the east of Brei Wick. Fragments of the sandstones are seen adhering to the felsite, which have been slightly indurated by the intrusive mass. On the west side of the felsitic intrusion, the sandstones are repeated with a westerly dip, and they are succeeded by the beds of coarse and fine tuff already described. These are overlaid in turn by coarse ashy sandstones, in which masses of tuff are curiously intermingled with layers of sand in the same bed. Grey sandy flags rest on these ashy sandstones, which are abruptly truncated by a fault bringing in the porphyrites. For a short distance the order of succession is disturbed by intrusive dykes; but near Tang Wick Ness the lavas are seen dipping in a north-west direction.

In the little bay beyond Tang Wick Ness a bed of dark purple diabase-porphyrite passes underneath coarse volcanic breccia, containing blocks of schist and porphyrites; the latter being most numerous. These included fragments of schist were doubtless derived from the sides of the old vents, and though we cannot now point to the sites of the volcanic orifices, still the existence of these blocks of schist in the tuffs clearly indicates that they must have pierced the metamorphic rocks of the district.

Not far to the west of this locality, pale slaggy porphyrites rest on dark purple lavas; the latter being overlaid near Stenness by coarse volcanic breccia,

occupying the centre of the syncline. From Stenness northwards towards Hamna Voe this volcanic breccia is traceable, being inclined at a gentle angle to the south of east and on the west side of the synclinal fold the porphyrites reappear, with a gentle easterly dip. They occupy the strip of rising ground bordering the sea at the Grind of the Navir, and in this neighbourhood the terrace-shaped features are most characteristically developed. Along the coast-line, from Stenness to the Grind of the Navir, there is an excellent exposure of the successive lava flows with few intercalations of tuff. The numerous isolated stacks and the more distant islet of Doorholm, which are formed of the same materials, plainly indicate the great denudation which the contemporaneous volcanic rocks have undergone.

A traverse along the south bank of Rooeness Voe confirms the general arrangement of the strata just described. The fault bounding the interbedded



Fig. 2.—Four successive lava flows overlaid by tuff. Ockren Head, Rooeness Voe, Rooeness Hill cliff in the distance.

series in Rooeness Voe, which has already been referred to, has not produced much effect on the inclination of the bedded masses. A short distance to the north-west of the fault, in a small stream draining two lochans, a section is exposed of red micaceous flaggy sandstone, overlaid by coarse tuff, dipping to the north-west at an angle of 3°. Following the coast-line, we have a continuous exposure of diabase-porphyrites, lying nearly flat or at gentle angles, till we reach Ockren Head at the mouth of the Voe, where the lava flows are admirably shown, piled on each other in regular succession. On the headland and also in an outlying stack to the north, there are four sheets of lava overlaid by coarse tuff. The diabase-porphyrites present the usual scoriaceous character on the upper and under surfaces of the flows, and they likewise thicken and thin out rapidly. The lavas have a purple tinge, and perhaps

appear more sombre than they really are when contrasted with the bright red cliffs of granite on the opposite side of the Voe. Some of the beds are highly involved, and show clearly how the partially solidified crust has been caught up and rolled forwards in the advancing current of the still molten lava.

From the evidence afforded by these sections, it is manifest that in the peninsular tract of Northmavine, west of Hillswick, there is an important development of ancient lavas and tuffs, which attain a thickness of not less than 500 feet. The absence of any intercalations of sandstones, flagstones or shales, save near the fault at Brei Wick and Rooeness Voe, is also a feature worthy of notice, as indicating that the subaqueous eruptions must have been well-nigh continuous for a time in that portion of the basin.

The interbedded volcanic rocks which now fall to be described, occur in the midst of a great series of sedimentary deposits, in the peninsular tract of ground lying to the west of Weisdale. These sedimentary deposits have undergone so much alteration that HIBBERT regarded them as forming part of the metamorphic series, though he noticed that the strike of the former was discordant with that of the latter. This classification was adopted till the summer of 1878, when in the course of our investigations we stumbled on a rich assemblage of plant remains in the beds north of Walls. Many of the specimens were badly preserved, but some of them were sufficiently distinct to permit of identification. Upwards of twelve specimens of *Lepidodendron nothum*, Unger and several examples of *Psilophyton princeps*, were obtained—forms which are typical of the Old Red Sandstone as developed in other parts of Shetland, Orkney, Caithness, and other regions. There can be no doubt, therefore, that these altered strata, which with the associated volcanic rocks cover an area of about 50 square miles, really form an important development of the Old Red Sandstone of Shetland. While engaged in mapping the boundaries of these altered strata, we detected certain lavas and tuffs which are regularly intercalated with the series; the former, however, differing considerably from their representatives in Northmavine. From their microscopic characters, as well as from their chemical analysis, it is apparent that the lavas have shared to some extent in the partial metamorphism of the area. But, before defining the localities in which they occur, it may be desirable to indicate their probable geological position.

Disregarding minor folds, the altered strata seem to form a great synclinal trough, the axis of which runs approximately from Fontabrough Voe on the west coast, east by the village of Walls to the head of Bixetter Voe. On the northern side of the syncline we have a gradually ascending series exposed on the coast from the cliffs of Sandness Hill southwards towards Fontabrough Voe. Similar ascending sections are to be met with on the shores of

Vaila Sound and Gruting Voe on the south side of the axis; but a large portion of the area on this side is occupied by a great sheet of intrusive granite, which will be referred to in a subsequent paragraph. By means of two powerful faults, the altered Old Red strata are brought into conjunction with the metamorphic series on the east and north sides, and hence the unconformable relation between the two is nowhere visible. A line drawn from a point not far to the east of Aith Ness in Aithsting, southwards by Bixetter and Symbister Church in Selie Voe, Sandsting, marks the course of the great north and south fault bounding the area on the east. On the north side the fault runs from a point west of Aith Ness in Aithsting, south-west by Sonso Ness, thence by Brindister, Burrafirth, to Snarra Voe and Sandness Hill. Over a great part of this peninsular tract the beds consist of grey and blue indurated sandstones or greywackes with green and pale shales. The sandstones are abundantly traversed with joints, which are frequently coated with peroxide of iron, and in places they have a marked schistose character. Sometimes the sandstones are converted into genuine quartzites, and the shales interbedded with them are distinctly cleaved. The plant remains which we found at various points on the moors between Walls and Sandness Hill occur in green and blue jointed sandstones weathering with a yellowish or pale white crust. At certain localities the beds are distinctly conglomeratic, especially on the rocky hills overlooking the head of Snarra Voe and West Burrafirth Voe. Characterised by massive bedding and containing more or less rounded pebbles of quartz, quartzites and various metamorphic rocks, they remind one of the thick-bedded conglomeratic sandstones at Lerwick on the eastern seaboard. Indeed, after several extensive traverses we came to the conclusion that much of the altered series west of Weisdale is the counterpart of the Lerwick series. The exact position of the latter in the order of succession which we established on the eastern seaboard will be readily seen from the following table :—

5. Flaggy series of Bressay and Noss, consisting of alternations of sandstones, flags and shales. At the base of Noss Head (577 feet) there is a zone of dark calcareous shale with limestone nodules, which has a striking resemblance to the well-known fish-bed of the Moray Firth basin.
4. Lerwick series, consisting of massive false-bedded sandstones, which throughout are markedly conglomeratic.
3. Rovey Head conglomerates.
2. Brenista series, consisting of well-bedded red flags.
1. Basement breccia.

If we are right in inferring from the resemblance in lithological characters and the identity of the plant remains, that the altered strata west of Weisdale

are on the same geological horizon as the Lerwick series, then we are able to fix the date of the ejection of the contemporaneous volcanic rocks in Aithsting and Sandness. The latter are admirably seen on the shores of North and South Clouster Voe, whence they can be followed north-eastwards towards Aith Ness. The volcanic rocks consist in that region of dark green diabase lavas, which only occasionally exhibit vesicular cavities on the surface of the flows. But from this feature, as well as from their perfect parallelism with the sedimentary strata, there can be no doubt of their contemporaneous origin. In chemical composition they are highly basic, and strongly resemble the diabase-porphyrites of Northmavine, though there is a difference in one important particular, which will be subsequently referred to. Again, on the western shores of Sandness the quartzites and flagstones are associated with bands of tuff, which are exposed on the coast at the mouth of Dale's Voe and further south near Watt's Ness. The volcanic ash can be traced inland in a north-east direction by the Stourbro Hill. The lavas and tuffs now referred to dip to the S.S.E., like the altered strata with which they are associated. They are not exposed on the south side of the synclinal axis; at least we saw no indications of them in the course of our traverses. Their absence may be accounted for by the occurrence of the great intrusive sheet of granite which was intruded along the lines of bedding at a period subsequent to the ejection of the lavas.

The small tract of unaltered Old Red strata at Melby contains no interbedded volcanic rocks, but in the Holm of Melby—a small island between the Mainland and Papa Stour—there is an interesting relic of volcanic activity. The arrangement of the strata is shown in the following section :—



Fig. 3.—Section across the Holm of Melby. 1, Sandstones and flags; 2, porphyrite.

Along the east coast runs a well-marked anticline of grey flags, which, towards the west, pass underneath a bed of dull purple porphyrite, forming the ridge in the centre of the Holm. This sheet of lava is overlaid by another series of grey flags, strongly resembling some of the flagstones in the Sound of Noss, east of Bressay. Possessing the usual amygdaloidal characters, this bed strongly resembles the type of porphyrites developed in Northmavine.

Crossing the Sound of Papa to the island of Papa Stour, further evidence is obtained of the intercalation of diabase-porphyrites in the flagstones, sandstones and conglomerates. The geological structure of this interesting island has been graphically described by Dr Archibald Geikie in the *Transactions* of this Society, and little else remains to be added to the account given by him.

In the course of our subsequent visit we obtained some additional evidence regarding the intrusive character of the sheet of felsite which forms such a prominent feature in the geology of the island. At various points on the coast-line, sometimes at the base of the cliffs, sometimes forming the whole cliff from top to bottom, there are certain red sandstones, flags and conglomerates which are clearly interbedded with purple slaggy porphyrites. That these lavas were ejected during the time of the formation of the sedimentary deposits is proved by the occurrence of blocks of diabase-porphyrite in the conglomerates. Neither the sandstones nor the interbedded porphyrites are traceable for any distance, as they are cut through and overlaid by a sheet of pink felsite, which covers nearly the whole of the island. The lavas occur in Hamna Voe on the south side of the island, on the shore east of the church in Housa Voe, on both banks of Culla Voe, and again on the headlands of Bordie in the north-west of the island.

The only relic of interbedded volcanic materials on the east side of Shetland is met with on the east coast of the island of Bressay in Noss Sound. Opposite the north end of the island of Noss, on the east side of the fault skirting the shore below Ander Hill, a bed of brecciated tuff about seven feet thick is associated with grey flags. The strata dip to the east at a low angle and are repeated by small faults, as shown in the accompanying ground plan.

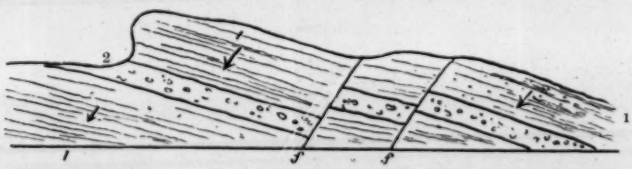


FIG. 4.—Intercalation of tuff (2) with grey flags (1), S.E. shore of Bressay.

There can be little doubt that this band of tuff is directly connected with the remarkable series of volcanic necks which occur not far to the south on the same island. When we come to describe the nature of the materials which now fill these vents, we shall see that it is highly probable that no lavas were ever ejected from these orifices. It is more likely that they mark but a feeble development of volcanic energy, during which occasional showers of tuff were spread over the sea-floor. If this be true, then, this band of tuff may be regarded as a relic of this sporadic outburst. Occurring near the top of the flaggy series of Bressay, it is evident that this tuff occupies a high geological position in the order of succession in the eastern seaboard. It is not improbable, therefore, that it may represent portions of the contemporaneous volcanic series of Papa Stour and Northmavine.

We have now completed the sketch of the interbedded volcanic rocks, and, from the foregoing descriptions, it is manifest that only portions of the ejecta-

menta discharged from the volcanoes of the period are still preserved to us. From the manner in which they are truncated by faults in Northmavine and overspread by intrusive felsite in Papa Stour, we are justified in inferring that their original limits must have been much greater than now. But the proofs

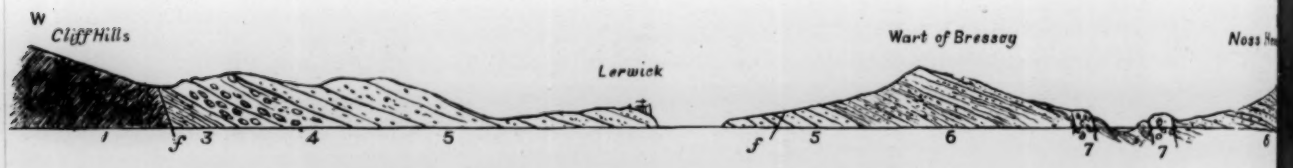


FIG. 5.—Generalised section across the Old Red Sandstone on the east side of Shetland, showing the position of the volcanic rocks in Bressay. 1, Schists of the Cliff Hills; 3, Brenista flags; 4, Rovey Head conglomerates; 5, Lerwick sandstones: 6, flaggy series of Bressay and Noss; 7, volcanic rocks; *f*, faults.

of volcanic activity are not confined to those materials which were accumulated simultaneously with the sediment on the sea floor. The phenomena connected with the intrusive igneous rocks furnish even more striking proofs of the display of volcanic energy which characterised that period.

B. *Intrusive Igneous Rocks.*

These may be grouped in three divisions—(1) Sheets, (2) Dykes, (3) Necks. Of these divisions the first is the most important, as the sheets cover extensive areas in Northmavine and Sandsting on the Mainland, nearly the whole of Papa Stour, the greater portion of Meikle Rooe and a portion of the island of Vementry. An interesting feature connected with these intrusive sheets is the evidence which they furnish of the vast amount of denudation which has taken place since Old Red times. It is only by working out the physical relations of these intrusive masses that we can form an approximate idea of the extent of this denudation.

By far the largest area occupied by these intrusive rocks is in Northmavine, where they extend from the northern headlands of the Mainland opposite Uya Island to Rooeness Voe and onwards to the Heads of Grocken, near Hillswick. The isolated columns of the Drongs are composed of the same intrusive rocks and likewise the eastern part of Meikle Rooe and the northern portion of Vementry. It is highly probable that the masses just indicated, though now isolated from each other, once formed parts of the same intrusive sheet. Lithologically, as well as microscopically, the rocks bear a close resemblance to each other. The length of this sheet, when measured from its northern limits to Vementry, is about twenty miles, and its breadth in Northmavine varies from three to four miles. This mass is brought into conjunction with the

metamorphic series at the Heads of Grocken by a fault, which is admirably seen on the shore.

In Meikle Rooe the granite mass is also faulted against the older rocks, which consist mainly of diorite with occasional patches of mica schists. In all likelihood, the fault at the Heads of Grocken and in Meikle Rooe is merely the northern prolongation of the great north and south dislocation bounding the altered Old Red strata west of Weisdale. On the shores of Rooeness Voe, however, and northwards by the Biurgs, on the eastern seaboard of Northmavine, the granite spreads over the ancient crystalline rocks in the form of a great sheet, without deflecting the strike of the metamorphic series, and terminates along the eastern margin in a great escarpment 200 feet high. The North-



FIG. 6.—Binary granite faulted against the ancient crystalline schists, Heads of Grocken, Northmavine. The Headlands of Stenness, and the Islet of Doorholm in the distance, formed of bedded lavas and tuffs.

mavine mass consists mainly of a binary granite or aplite, composed of quartz and pink orthoclase felspar, shading occasionally into salmon-coloured quartz-felsite. Generally the rock is coarsely crystalline and highly siliceous, and there can be no doubt that the mass must have consolidated under great pressure, though the materials under which it lay buried have been wholly removed by denudation. The presence of so much silica has no doubt retarded the general denudation of the Rooeness plateau, but it has been ineffectual in preventing the waste caused by the sea. But apart from the coarsely crystalline character of the rock, the marked columnar structure suggests the idea that it is a great intrusive sheet which has consolidated underneath the surface. Those who wish to study this feature would do well to sail down Rooeness Voe or along the shores of St Magnus Bay from the Heads of Grocken to Brei Wick (see *Sketch of Heads of Grocken*, fig. 6). Along the cliffs the observer is confronted by symmetrical columns rising from the sea-level, which are tra-

versed by a series of vertical joints. Hence it follows that the vertical face of the cliff is preserved, though constantly assailed by the sea and subjected to continual recession by the removal of huge slices of rock. Frequently the columns are isolated and left to battle with the denuding agencies as best they may. The columns of the Drongs are beautiful relics of the Rooeness Hill sheet which have hitherto been able to resist complete demolition.

We have already referred to the fact that the only place where this intrusive mass is seen in contact with the interbedded volcanic rocks of Northmavine is on the south bank of Rooeness Voe, where the latter are thrown down by a fault against the former. We have therefore no indication of the thickness of strata which originally covered the plateau. But, from the columnar structure, the coarsely crystalline texture, from the manner in which it spreads over the metamorphic series like a great cake, we have come to the conclusion that the Rooeness mass is an intrusive sheet which forced its way

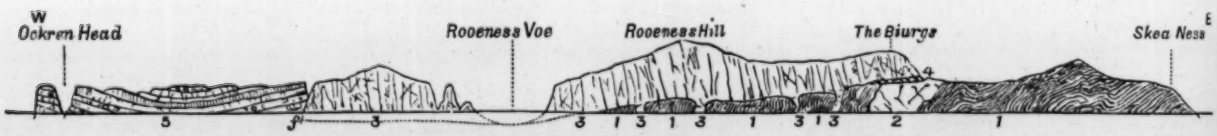


FIG. 7.—Section across Northmavine from Ockren Head to Skea Ness. 1, Metamorphic rocks; 2, serpentine; 3, granite and quartz-felsite; 4, breccia of serpentine fragments; 5, bedded porphyrite and tuff; *f*, faults.

upwards and laterally between the metamorphic strata on the one hand, and the members of the Old Red Sandstone on the other, at the time when the Mainland lay buried under the deposits which accumulated during that period. It is right to state, however, that, so far as our observations went, there are no beds underlying this igneous mass which could be referred to the Old Red Sandstone. At one locality, to the north of Colafirth Voe, a curious brecciated serpentinous mass occurs, which might, on further examination, prove to be a basal breccia of this age. Be this as it may, it is evident that the underlying platform consists mainly of diorite and various metamorphic rocks. The foregoing conclusion is confirmed, as we shall presently point out, by an examination of the relations which the Sandsting granite mass and the Papa Stour felsite bear to the Old Red strata.

The age of the granite mass of Sandsting is placed beyond doubt by a study of its relations to the altered Old Red strata of that district. It covers a triangular area, extending from Selie Voe to Gruting Voe. A portion of the sheet is also met with in the south-east of the island of Vaila. When measured along a line from Vaila to Selie Voe, the mass is 6 miles long, and its greatest breadth is about 4 miles. Presenting the same columnar structure as the Rooeness sheet, it immediately suggests the idea of a common origin. Lithologically it approaches the type of an ordinary granite, save at certain

localities, where, through the disappearance of the mica, it resembles the binary granite of Rooeness Hill. The upper limit of the sheet is clearly defined by the altered Old Red strata between Gruting and Selie Voes. Along this line the observer cannot fail to note how the slope of the upper surface of the intrusive sheet coincides with the angle of inclination of the sedimentary rocks. This feature is admirably displayed on the east bank of Gruting Voe, at the foot of Cullswick Hill. The hardened quartzose flags dip to the north at an angle of about 20°, which is about the inclination of the boundary line between the two. When followed along the junction line, however, the granite cuts across the successive beds, resembling, as we shall see, the behaviour of the sheet of pink felsite on Papa Stour. But in addition to this fact, it frequently



Fig. 8.—Junction of granite and altered Old Red Sandstone strata in Gruting Voe.

happens that the altered Old Red strata and the intrusive sheet are firmly welded together along the junction. In some instances it is possible to dislodge fragments a few square inches across, showing the junction between the two—a phenomenon which conclusively points to the intrusive character of the mass. There is no passage from the sedimentary rocks into the granite, indicating a probable metamorphic origin. On the contrary, the junction line is sharply and clearly defined. This feature, which is characteristic of the Rooeness and Sandsting sheets, is thus referred to by Dr Heddle—"Holding firmly to the view which regards much of the granite in Scotland as the completion of the metamorphism of the gneiss, I am unable to adopt for a moment any such view as regards the granite of Shetland. The nature of the rock itself, the abutments of the stratified rocks against its flanks and the disturbances it has produced among their adjacent layers forbid such a view."*

The island of Papa Stour is covered for the most part with a sheet of pink spherulitic felsite, forming noble cliffs which rival those of Rooeness Voe and the Heads of Grocken. The same columnar structure is everywhere apparent, not only in the island itself, but in the outlying stacks and skerries, which have been severed from the main sheet by denudation. Fortunately the evidence is sufficiently clear to show that this sheet must have been injected between the underlying diabasic lavas and tuffs and an overlying series of sedimentary deposits, only a fragment of which has escaped denudation. In his

* *Mineralog. Mag.*, vol. ii. p. 160.

description of the geology of Papa Stour, Dr Archibald Geikie has referred to two sections, one on the north side of Hamna Voe and the other on the cliffs at the headland of Bordie, where the bedded lavas and grey flaggy sandstones are traversed by this sheet of pink felsite. In the course of our subsequent visit, we observed that, in Culla Voe, the sheet steals across the edges of the lavas, while a thin lenticular offshoot from the main mass is forced in like a wedge at a lower level between the diabase-porphyrites. Further, on the south-eastern headlands, about a mile east of Hamna Voe, the pink felsite cuts



Fig. 9.—Pink spherulitic felsite showing marked columnar structure, north-west side of Papa Stour with outlying stacks—Foula in the distance.

across the sandstones, and passes from a lower to a higher horizon, as shown in the accompanying section. These and other sections which might be adduced, plainly indicate the intrusive character of the Papa Stour sheet, since it not only occurs on various horizons, but frequently eats its way upwards, when traced along the base of the cliffs. There can be no doubt that the sandstones and conglomerates with the associated lavas form the platform over which the



Fig. 10.—Pink felsite injected among red sandstone, on shore one mile east of Hamna Voe, Papa Stour. 1, Red and purple amygdaloidal diabase-porphyrites ; 2, red sandstone and flags ; 3, pink spherulitic felsite.

felsite spreads. It is equally clear, however, from the evidence obtained at the Horn of Papa, that the sheet must have been covered by sedimentary deposits. There, on the cliff top, the pink felsite is overlaid by a patch of red felspathic sandstones which are nearly horizontal. The sandstones in immediate contact with the felsite have been hardened and altered to some extent by the intrusion of the igneous mass, and in some places portions of the sandstone and felsite may be seen adhering together, clearly showing the effects of contact metamorphism. The occurrence, therefore, of this isolated patch of sandstone is invested with special interest, inasmuch as it helps us to realise the denudation

which has taken place. It is evident that the sandstones must originally have covered the whole of the sheet, and may probably have been continuous with the sedimentary deposits of the Mainland. But though the evidence now adduced shows that the felsite has been injected among the members of the



FIG. 11.—General section across Papa Stour. 1, Red sandstones and flags; 2, purple diabase-porphyrites; 3, great sheet of pink spherulitic felsite.

Old Red Sandstone, there is an important lithological difference between the Papa Stour rock and the granitoid masses of Sandsting and Rooeness Hill. This divergence will be discussed when we come to treat of their microscopic characters.

2. *Dykes and Veins.*—One of the most interesting features connected with the great intrusive sheets is the number and variety of the dykes and veins radiating from them as centres. Along the boundary of the Northmavine sheet from North Rooe southwards by Hillswick, Mavis Grind, to Aith Voe in Aithsting, these dykes occur in great numbers. Throughout that wide area they traverse the ancient crystalline rocks, the diorite and the altered Old Red strata. In addition to this, we find thin veins and bosses of the same materials penetrating the interbedded volcanic rocks between Brei Wick and Stenness. This latter point is of some importance, as it shows that the intrusion of the sheet, with its branching veins, was subsequent to the ejection of the basic lavas and tuffs. In many cases it is possible to trace the branching veins till they coalesce with the parent sheet; but more frequently they are completely isolated at the surface, though it is probable that a subterranean connection may exist. The same phenomena are repeated in the case of the great mass in Sandsting and in a less conspicuous form in connection with the Papa Stour sheet. The dykes and veins belonging to the acidic series may be grouped under three divisions—(1) Binary granites and ordinary ternary granites, (2) Quartz-felsites, (3) Rhyolites. In the case of the first group, the dykes still preserve the lithological character of the parent sheet, being coarsely crystalline and consisting mainly of pink orthoclase felspar and quartz with hardly any mica. Some characteristic examples occur in Northmavine, more especially along the coast-line from Mavis Grind to Hillswick. Indeed, the isthmus at Mavis Grind exhibits a curious network of these granitoid dykes interlaced with the diorite. The quartz-felsites are still more numerous than the preceding group. Possessing a fine-grained ground mass with quartz, in distinct crystals or amorphous forms, they are readily distinguishable from the granitoid type. They are typically developed on the shores of Gruting Voe in Sandsting, in

contact with the granite mass, and in the altered Old Red strata at some distance from the main sheet.

By far the most interesting of these intrusive dykes, however, are the rhyolites, which are conspicuously developed in the small island of Papa Little, on the neighbouring shore of the Mainland, and also round the granite mass of Sandsting between Bixetter Voe and Loch Skeld. Possessing a fine-grained semi-vitreous texture, they exhibit in hand specimens a characteristic banded arrangement of the partially devitrified felsitic matter. The constituent bands sometimes display slight variations of tint, which serve to make them more discernible by the eye. This banded arrangement, which, as we shall presently show, is due to fluxion structure, maintains a constant direction in the case of the dykes in the south-east corner of Papa Little. Even when the main dyke sends branching veins into the adjoining strata, the lines of flow have the same trend in the offshoots as in the parent dyke,—a feature which is interesting and suggestive. The rhyolites are usually of a pale grey or yellowish colour, but some of them possess a marked pink or flesh-red tint. This interesting series was detected by us in the course of our third visit to Shetland when tracing the faults bounding the altered Old Red strata west of Weisdale. A subsequent visit was paid to the islands solely for the purpose of determining whether they might represent acidic lavas which had been ejected at the surface. The microscopic examination plainly showed that some of the dykes possess fluxion structure in a remarkable degree, and we were therefore anxious to learn whether this might be due to extravasation at the surface and the rapid consolidation of the glassy magma. During this visit our observations were mainly confined to the magnificent sections round the southern shores of Papa Little, where the strata consist of well-bedded but considerably altered flags and shales belonging to the Old Red Sandstone. The two great faults bounding the altered Old Red area in the Mainland cross each other in this island, the one trending towards the north in the direction of Meikle Rooe, while the other preserves an E.N.E. direction. Only the south half of the island is made up of strata of Old Red age, the remainder being composed of gneissose rocks belonging to the series which is so well developed in the centre of the Mainland. The rhyolite dykes are most strikingly represented on the south-east shore, northwards to the point where the fault brings the Old Red strata into conjunction with the metamorphic series. The altered flagstones have a persistent strike about N. 10° W., which is more or less parallel with the north and south bounding fault, and they dip about W. 10° S. at angles varying from 70° to 80°. This strike is quite abnormal, however, and is evidently caused by proximity to the great north and south fault, for when we cross to the south-west shore of Papa Little the strike of the flagstones is E.N.E., which is identical with the trend of the altered Old Red strata over much of the area west of Weisdale.

On the south-west shore the dip of the strata varies from S.S.E. to S.E. The indurated flagstones and shales pierced by the rhyolites are frequently coated with a green chloritic or serpentinous substance. The dykes are of variable breadth, some of them measuring 12 feet across, while others are considerably in excess of this amount. Generally they preserve a course more or less parallel with the lines of bedding of the flags and shales, but not infrequently they pass transgressively across the edges of the flags. In one instance, the dyke enclosed lenticular patches of altered shales, which were injected with thin branching veins of rhyolite, varying from a few inches to 2 feet in breadth. When traced northwards, this mass rises along the edges of the shales on the cliff. Not far to the north of this locality similar evidence is obtained on the shore of the intrusive character of the rhyolites. The following ground plan exhibits the relation of the intrusive dykes to the Old Red strata on this part of the shore.

At Aith Ness some of the dykes exhibit in a less perfect form the banded structure of those just described, and in this case also they occur close to the north and south boundary fault. It is possible that in some cases this fluxion structure might be partly due to shearing, which might have caused subsequent rearrangement of the materials in connection with the faulting and metamorphism

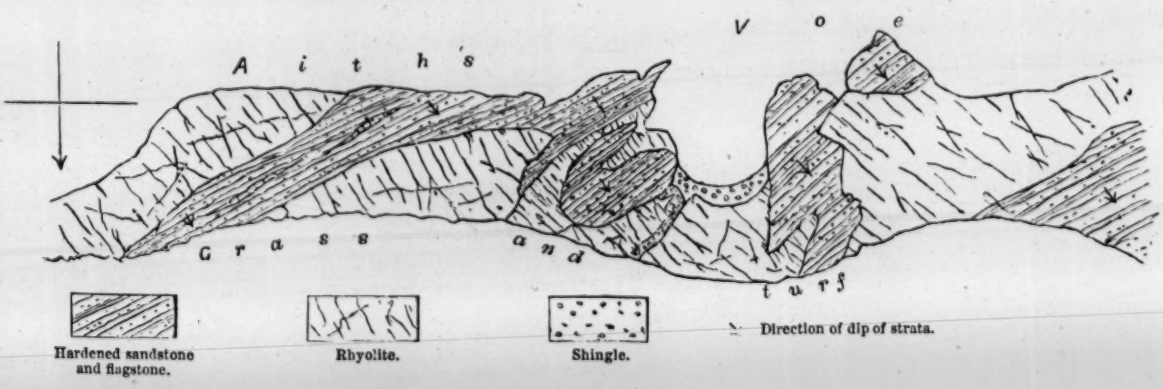


FIG. 12.—Ground Plan of rhyolite dykes intruded among Lower Old Red Sandstone strata, south-west shore of Papa Little, Shetland.

of the beds; but we shall now point out that the same feature is observable in the dykes near Loch Skeld, about 3 miles from the bounding fault. In the Laxa Burn, to the south-west of Bixetter Voe, a dyke of rhyolite was observed, which, on the roadside near the cottage as well as in the burn below the road, merges into a crystalline granitoid rock with quartz, felspar and mica. Again, in the neighbourhood of Loch Skeld, near the granite boundary, we found typical examples where the dykes display fluxion structure as perfect as in Papa Little.

The three preceding types of intrusive veins belong to the acidic series, and closely resemble each other in chemical composition, as may be seen at a glance

by referring to the table of chemical analyses appended to this paper. Nay further, it may be noted that the rhyolites are, so far as their chemical composition is concerned, closely allied to the great intrusive sheets. Taking this important point into consideration, as well as their behaviour in the field, it is evident that the former are merely offshoots from the latter. We are inclined to believe that the rhyolites formed ducts leading in all probability to the surface, and that in these subterranean fissures the banded structure was originally developed. Had the molten matter reached the surface, it would have been ejected as highly acidic and glassy lava. When we come to describe the microscopic characters of these rocks, it will be seen that they have undergone considerable devitrification.

But there is another series of dykes of a highly basic type, which have been injected through the great sheets of granite and quartz-felsite, and are therefore of a later date. This material is also met with in the form of bosses

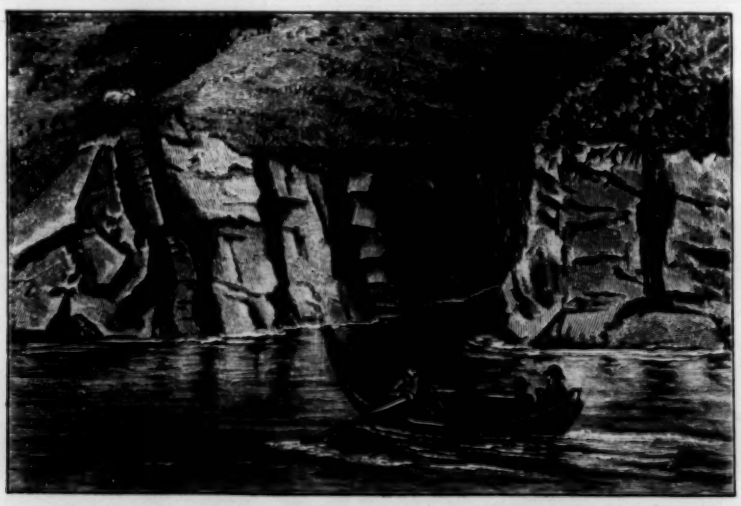


FIG. 13.—Diabase dykes traversing pink granite, north shore of Rooeness Voe, Northmavine.

piercing the granitoid masses, as in the case of Skeld Hill in Sandsting. These rocks consist of diabase of a fine-grained character when occurring in the form of dykes, but very granular and coarsely crystalline when developed in bosses. The dykes are prominently developed on the Rooeness plateau, where they have been noted by HIBBERT and Dr HEDDLE, on the shores of Rooeness Voe, and on the cliffs of Meikle Rooe. At these localities they have a north and south trend; and, owing to their dark colour, they form a striking contrast to the pink granite in which they occur. Sometimes, owing to rapid decay, they leave great clefts, indicating their course; sometimes they project above the general level of the acidic rock on either side. In the Sandsting granite mass we likewise noted several dykes of the same rock. In the burn near Garder House, close to Selie Voe, several examples occur. The granite and

felsite through which these diabase rocks are injected are occasionally very hornblendic, but not always so. Notwithstanding this feature, the boundary is clearly defined. On the Skeld Hill the boss of diabase has a well-marked boundary separating it from the granite which surrounds it. In this instance the granite is micaceous, with pink orthoclase felspar and quartz, the mica being very dark-coloured and abundant close to the basic rock. The diabase, on the other hand, hardly contains any quartz, and the felspar is only sparingly developed; while the green mineral is very abundant. In a subsequent paragraph we shall point out the resemblance in chemical composition, and, to a certain extent, in microscopic characters, between these basic intrusions and some of the diabase lavas. From the manner in which they traverse the intrusive sheets, there can be no doubt that they mark a later phase of volcanic activity, if, indeed, they do not mark the close of volcanic action in the Old Red Sandstone of Shetland.

3. *Necks.*—The occurrence of volcanic pipes of Old Red age in Shetland is another proof of the manifestation of volcanic activity which characterised that

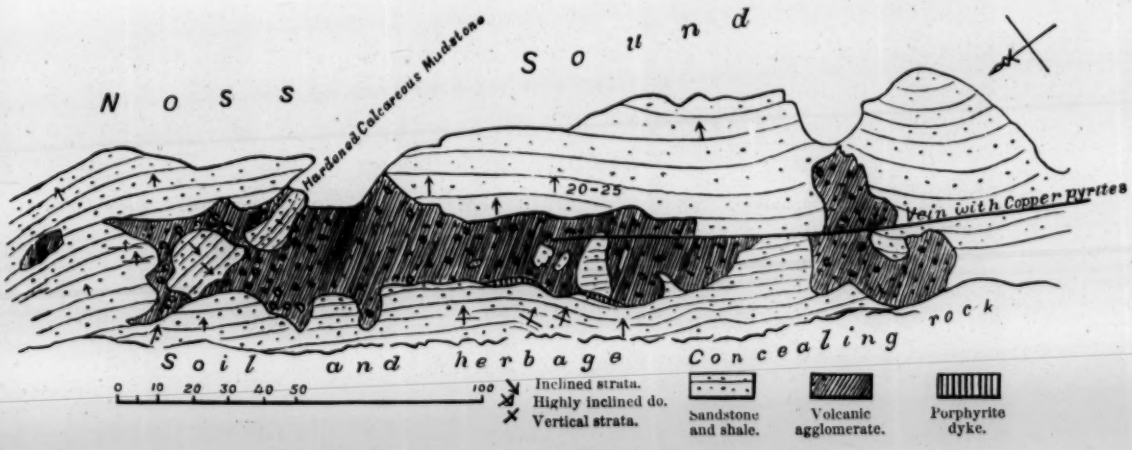


FIG. 14.—Plan of Volcanic Pipes or Necks on East Shore of Bressay.

period. Strange to say, they occur on the eastern seaboard of Shetland, where the interbedded volcanic materials hardly exist. So far as our observations have gone, no trace of these volcanic orifices is to be found in the western districts of the Mainland or the adjoining islands, where the igneous rocks are best developed. At the entrance to Noss Sound, on the south-east shore of Bressay, and also in the island of Noss, a series of necks is exposed. The vent in the island of Noss was noted by Dr HEDDLE in 1848,* though, so far as we are aware, no previous description of it has been given. The necks are arranged in a linear manner, and have evidently come to the surface along a line of fissure.

* *Mineralog. Mag.*, vol. ii. p. 253.

The beds surrounding the necks consist of red sandstones, which are much shattered and baked along the lines of junction with the agglomerate. They dip seawards (towards the east) at angles varying from 20° to 25°; but towards the edge of the fissure they are highly inclined. When the sandstones are followed inland, the alteration which is so apparent at the line of junction gradually disappears. As may be seen from the accompanying ground plan (fig 14), the outline of the vents is very irregular.

The materials filling the vents consist of a coarse agglomerate, made up of angular fragments of sandstones, flags and shales, imbedded in a finely-comminuted paste. Occasionally large masses of the surrounding sandstones are enclosed in the agglomerate, which are highly crystalline. Besides these, there are masses of red calcareous and highly-baked mudstones, which have been torn from the sides of the vent. No bombs of porphyrite occur in the agglomerate,—at least, none was observed by us. A vein of porphyrite a few inches thick is traceable along the margin of the orifice for a short distance, and coatings of a diabasic lava occur on the surfaces of the indurated sandstones. We also noticed a thin vein of copper pyrites traversing the agglomerate and the altered sandstones.

Crossing the Noss Sound, another neck is visible, which resembles that just described in the nature of the material filling the vent and in its mode of occurrence. Round the neck the gradual folding inwards of the flags near the edge of the agglomerate is worthy of note, as it forms a characteristic feature of the stratified rocks in immediate contact with the Carboniferous volcanic vents in central Scotland. From the nature of this volcanic agglomerate it is highly probable that no lavas were ejected from these orifices. It is more likely that they served mainly as blow-holes, discharging occasionally showers of triturated materials derived from the sides of the vents.

We shall now briefly summarise the succession of events as indicated by the volcanic phenomena described in the foregoing pages. The earliest ejections consisted of basic lavas and tuffs, which were spread over the sea-floor, and in several instances were intercalated with the ordinary sediment. In North-mavine the volcanic accumulations were nearly continuous, save towards the horizon of the lowest beds, where flagstones and ashy sandstones alternate with the lavas. In the Aithsting and Sandness district the ejections were limited to a few sheets of diabase and some bands of tuff, which are interbedded with a great succession of altered sandstones, flags and shales. The sheet of porphyrite in Melby Holm indicates a recurrence of volcanic activity, which became more pronounced as the conglomerates, sandstones and flags of Papa Stour were deposited. In the latter case the discharge of volcanic materials must have been intermittent. The band of tuff and the necks in Bressay

indicate a sporadic outburst during the deposition of the flaggy series of Bressay and Noss.

The discharge of these highly basic lavas and tuffs and the deposition of the associated sediment, were followed by the injection of three great sheets of highly acidic rocks. The relations of the sheet in Papa Stour to the basic rocks plainly show that the eruption of that mass was later than the ejection of the lavas. Similar evidence is supplied by the granite mass in Sandsting, and there is every probability that the great Rooeness plateau was erupted at a later date than the basic lavas of Northmavine. Numerous veins of granite, of quartz-felsite, and of rhyolite radiate from these intrusive sheets, which doubtless belong to the same period of intrusion. The last phase was characterised by the eruption of a series of highly basic rocks, consisting of diabase, which traverse alike the ancient crystalline rocks, the Old Red strata and the great intrusive sheets.

II. Microscopic Characters.

The microscopic examination of the bedded lavas proves that there is a considerable difference between the so-called porphyrites and the diabase rocks, which both occur in the series. A typical example of the former group, taken from the neighbourhood of Ockren Head in Rooeness Voe, shows that it is composed mainly of very minute columnar crystals of plagioclase felspar, which, as a rule, are much altered, and only occasionally show traces of the twin striation. Between these closely aggregated crystals there is a fine ground mass, and some of the minute interspaces are also occupied with a bright green decomposition product, which may be green earth. After the felspar, however, magnetite is the most abundant mineral,—so much so, indeed, that it might be grouped with the class of felspar-magnetite rocks described by Dr Archibald Geikie in his paper on the "Carboniferous Volcanic Rocks of the Basin of the Forth."*

The sections prepared from the lavas in the altered Old Red area, between Clouster and Aith Voes, show that plagioclase felspar is the chief constituent. Augite, however, is also present, though it is only occasionally recognisable, by far the larger portion having been converted into chlorite. In one instance where this alteration has been considerably developed the augite has a granular appearance; but in other sections a few larger crystals of augite remain which are quite distinguishable. The magnetite, which is also largely distributed, has been converted to a great extent into limonite. This type is a true diabase, and were it not for the great alteration which has taken place in the pyroxenic mineral, it might be compared with some basaltic lavas of later palæozoic age.

* *Trans. Roy. Soc. Edin.*, vol. xxix. p. 508.

There is one noteworthy feature connected with the sections prepared by us from the Shetland lavas, and that is the absence of olivine in recognisable forms. In this respect they differ from the diabase lava of the same age in Shapinshay, Orkney, which we detected in 1879. One of the sections from this locality shows that, in addition to the plagioclase felspar, there is much olivine distributed in crystals and crystalline grains, which, for the most part, has been converted into serpentine. Chlorite is also present, but the augite is hardly represented at all. The magnetite, which is very abundant, frequently envelopes the crystals of olivine either wholly or in part only. This type is very different from any we have met with in Shetland. It might be termed a felspar-diabase, rich in olivine and poor in augite.

On referring to the table of analyses appended to this paper, it will be seen that of the two types—the one taken from the porphyrites in Northmavine, and the other from the diabase lava in Clouster Voe—the latter is the more basic. The proportion of silica in the porphyrite lava from Rooeness Voe is 51·82, while in the diabase from Clouster it is 48·36 per cent. The alumina in the former is 14·14, while in the latter it is 19·73 per cent. Another difference of some importance is in the relative quantities of magnesia: in the porphyrite lava it is 1·76, while in the diabase lava it amounts to 5·97 per cent. It would seem, therefore, that the diabase lavas from the altered Old Red area west of Weisdale were not only more basic originally, but the greater proportion of magnesia points to considerable alteration at a subsequent date.

A section of volcanic ash from Dales Voe, Sandness, when examined microscopically is found to consist of angular and subangular quartz grains, with a few fragments of orthoclase and plagioclase felspar. It also contains fragments of felsite, and a rock exhibiting an ill-defined micro-crystalline structure resembling that of some of the devitrified rhyolites. A fine dusty felspathic substance separates the individual grains.

It may be more convenient to describe here the microscopic characters of the intrusive diabase rocks, as they have close affinities both chemically and microscopically with the interbedded lava just referred to. These affinities are all the more interesting when we remember that the respective eruptions of the two groups were separated by a considerable interval of time, during which highly acidic rocks were ejected. The microscopic characters of the diabase from the boss in Sandsting resemble those of the dykes in Northmavine, with this exception, that the former are more coarsely crystalline. The sections from the Skeld Hill show that the felspar crystals are much decomposed, but in some cases it is possible to determine that they are plagioclase. Instead of presenting the usual clear faces, they have a dusty brown appearance, which has almost obliterated their twin structure. It is observable that the triclinic felspars, though larger than in the interbedded lavas, do not

form the main constituent. They are associated with a green fibrous mineral, which is largely represented, and has apparently replaced the augite. In one of the sections, the augite occupying the interspaces still occurs in forms which are recognisable; parts of the original crystals being quite fresh, while the remainder has been converted into chlorite and a yellowish green mineral which may be epidote. The unaltered portions show the characteristic play of colours with polarised light. A little magnetite is diffused through the sections, but to a much more limited extent than in the diabase lavas. It occupies quite a subordinate position compared with the felspar and the green chlorite mineral. We have already called attention to the fact that the boundary line between the diabase and the granite is well defined. A section of the granite from the junction contains triclinic felspars, clear quartz with fluid inclusions, and mica partially converted into a green decomposition product. Numerous specks of limonite occur, resulting from the hydration of the iron oxide. The rock associated with this in the same microscopic section is a diabase similar to those described. It contains no quartz, and the augite is faintly recognisable.

The sections taken from the stream near Garder House, on the west bank of Selie Voe, are coarsely crystalline like those from Skeld Hill. The plagioclase felspars are much kaolinised, and the pyroxenic mineral has undergone intense alteration.

Compared with these, the sections taken from the dykes in Northmavine traversing the binary granite and felsite are exceedingly fine-grained. In one instance, the crystals of plagioclase are very fresh, and the interspaces between the crystals are filled with a bright green mineral, probably chlorite, there being no fresh traces of the original augitic constituent. Magnetite is not abundant, and small needles of apatite are disseminated through the mass. Another example taken from Rooeness Voe exhibits much granular augite along with the triclinic felspar, which has only undergone slight alteration. Magnetite is also present in very small grains.

The chemical analysis of a typical example of the Skeld Hill rock proves that it is closely allied to the basic lavas; the proportion of silica being 50·58 per cent. The percentage of magnesia is even larger than in the two examples of the interbedded lavas, amounting to 8·90 per cent. This feature plainly indicates the great alteration which the pyroxenic mineral has undergone, and the consequent development of magnesian silicates. It is worthy of note that while the specific gravity of the bedded lavas is 2·7, that of the Skeld Hill rock is 2·9 per cent.

The microscopic characters of the great intrusive sheets in Northmavine and Sandsting have many points in common. A section from the Heads of Grocken shows that the rock is coarsely crystalline, consisting essentially of red orthoclase and quartz. The felspar is much kaolinised; but in one instance

a crystal of orthoclase displays the Carlsbad type of twinning, polarising with different colours on different sides of the median line. The quartz occurs in grains and in crystals, clear and colourless, with numerous fluid inclusions. A small quantity of apatite is present in the section. There is no trace of any felsitic ground mass, and it is therefore evident that the rock most nearly approaches the character of a binary granite or aplite. Another section from the north bank of Rooeness Voe exhibits the same coarsely crystalline character as the preceding example; the felspar predominating over the quartz. Besides the orthoclase, which is also kaolinised, there is some microcline which, with polarised light, displays that peculiar rectangular arrangement of the striations traversing the mineral. Magnetite is also present, merging in some instances by hydration into limonite. The microscopic examination of sections taken from various localities throughout this mass only confirms the conclusion previously arrived at by Hibbert and Dr Heddle. The rock is essentially granitic, but owing to the singular absence of mica over the greater portion of the sheet, it is different from the older granites in Shetland, represented by the masses at Dunrossness and Bixetter Voe.

A section taken from near the margin of the Sandsting sheet in Gruting Voe contains much orthoclase which has been considerably kaolinised, large grains of quartz, and a little black mica. In short, it is a typical granite. Another specimen from the hills west of Skeld closely resembles the foregoing, with the addition of a small quantity of microcline. At Laxa Burn the rock consists of an admixture of red orthoclase and quartz.

The rock occurring near the diabase on Skeld Hill shows, under the microscope, prisms of orthoclase and plagioclase; the latter predominating, and less altered than the former. With these are associated clear quartz and dark mica, which are strongly dichroic. Needles and prisms of apatite occur abundantly in the section, while magnetite is also present along with some crystals of sphene. A specimen, not far removed from the foregoing, exhibits a fair proportion of green hornblende, which is dichroic, along with biotite, the other constituents being the same. In the sections prepared from the Sandsting sheet no trace of a felsitic ground mass has been observed. The only noteworthy microscopic difference between the Sandsting and Rooeness sheets is in the development of mica and hornblende in the former mass.

Far more interesting and exceptional are the microscopic characters of the Papa Stour sheet of pink or salmon-coloured felsite. Instead of presenting a marked crystalline aspect, it shows a felsitic ground mass of a reddish-brown colour, in which few felspar crystals are discernible. This ground mass is highly decomposed, and hence, even with a high power, it is impossible to define the fine granular constituent, as the base has little action on polarised light. The characteristic feature of the rock is the well-marked spherulitic

structure which it presents under the microscope. A section prepared from the knobs of this rock, near the church, on the east side of the island, displays this spherular arrangement with singular beauty. The spherulites do not traverse the section in regular bands, but in wavy lines and in groups. No nucleus is observable in the centre of the spherules, nor are they enclosed by a periphery, as in the spherulitic glassy lavas of younger date. When magnified 120 diameters, some of these spherular developments exhibit very clearly the fine radial fibres diverging from a common centre, while others have lost all traces of these fibres. In the latter case they are supplanted by an exceedingly fine-grained ground mass, but the rude outlines of the original spherules are still visible. The ground mass is stained by minute ferruginous particles, resulting from the decomposition of iron pyrites. There are numerous small nests or cavities in the ground mass, filled chiefly with quartz of secondary origin and small crystals of orthoclase.

Another section, taken from the cliff at the Horn of Papa, exhibits a similar spherular structure, though of a less perfect type. The divergent fibres are not so characteristically developed, and in the parts of the section where they are absent, the ground mass is more granular. The nests filled with secondary quartz do not form such a striking feature in this section; but one large crystal of clear quartz, with fluid inclusions, occurs in the mass.

Attention has been previously directed to the microscopic characters of this felsite by Dr Archibald Geikie, who has pointed out the spherular groupings of the constituents and the absence of any crystalline structure in the rock. From the evidence now adduced, we are inclined to believe that the felsite originally possessed a vitreous character, which has to a large extent disappeared through devitrification. In all likelihood the great alteration which the rock has experienced may have been partly coincident with, and partly subsequent to, this molecular change. If the vitreous material had reached the surface originally, it would have been ejected in the form of a glassy lava.

The dykes radiating from the intrusive sheets present microscopic characters of a varied type. The coarse-grained aplites or binary granites are identical with the Northmavine and Sandsting sheets. A typical example occurs at Mavis Grind, in which the felspar is mainly orthoclase with some Carlsbad twins. Some microcline is also present, but the felspars have undergone considerable alteration. The quartz occurs in isolated crystals and in groups enclosed in the felspars. A number of sections of the quartz-felsites have been prepared, displaying very uniform characters. A typical example from Aith Ness, in Aithsting, shows a micro-crystalline ground mass of felsitic matter, with small crystals of orthoclase porphyritically developed. Quartz occurs in small grains and nests, and magnetite is also present in minute grains. Another sec-

tion from a dyke close by the former locality exhibits a similar ground mass, but more coarsely crystalline, which is traversed by veins of secondary quartz and laminæ of chlorite, with magnetite grains more abundantly developed. All the specimens have been much kaolinised.

The rhyolites possess certain microscopic characters which readily distinguish them from the preceding group. They exhibit fluxion structure of a more or less perfect type and possess a micro-crystalline base. In this base, crystals and grains of quartz and felspar are arranged in parallel but wavy lines, round which the felsitic matter curves in continuous streams. The parallel and wavy bands of felsitic matter vary considerably in density. Some of them are extremely fine-grained, parts of them remaining dark under crossed nicols. The coarser bands do not remain dark with crossed nicols, and with polarised light many of the particles exhibit the play of colours characteristic of quartz. It is evident, therefore, that much of the base of the coarser bands consists of minute grains of quartz. The felspar and quartz frequently exhibit rounded edges in the midst of the streams of devitrified matter. Another feature of these ancient rhyolites is the absence of microlites in the ground mass, which are so characteristic of the younger vitreous rocks.

A section (59 *e*) from the north-east corner of Papa Little exhibits most of the foregoing characters. The wavy bands of micro-felsitic matter are admirably shown, along which are arranged lines of quartz and felspar, but not continuously. Plagioclase is of less frequent occurrence than the orthoclase, and many of the quartz and felspar crystals have distinct rounded edges. A few crystals of iron pyrites occur in the section, which decompose into fine grains of limonite. A green dichroic mineral, probably hornblende, occurs in one of the denser bands. There are also minute grains of viridite, which are evidently decomposition products. No microlites are observable in this section. In one section (2 *e*), taken from a dyke close by the foregoing instance, the bands of fine micro-felsitic matter enclose small oval-shaped masses of a coarse-grained material otherwise similar in character to the surrounding base. The quartz is frequently elongated in the direction of the flow of the molten matter. Throughout the base there are abundant dark grains, probably opacite. The section (3 *e*) from the same neighbourhood possesses a very fine-grained and dense band of micro-felsitic matter, in which a prism of orthoclase lies obliquely across the direction of the flow, round which the stream of devitrified matter curves in continuous lines. With crossed nicols, this dense band exhibits patches which remain dark when the stage is rotated.

The section from near Skeld, in Sandsting, close to the edge of the granite mass, exhibits very distinct fluxion structure, but the micro-felsitic base con-

tains hardly any crystals of quartz and felspar. The sections from Laxa Burn, near Sand Church, in Sandsting, display similar characters.

From the foregoing descriptions it cannot be doubted that this well-marked fluxion structure is due to movement of the molten magma which originated in the fissures radiating from the intrusive sheets.

The evidence seems to point to the conclusion that the materials originally existed in a glassy form, and that the rock when it consolidated was a rhyolite. Since that period a process of devitrification has been in operation, which has converted the glassy matrix into the micro-felsitic matter. The fact that only portions of the denser bands remain persistently dark under crossed nicols, while the coarser bands transmit the light, would seem to indicate that the devitrification has advanced so far as nearly to destroy all traces of the original glass. Nay more, in one instance (65 *e*), from near Aith Ness, in Aithsting, the fluxion structure is hardly traceable, save with polarised light. This section shows a crystalline felsitic ground mass, with occasional crystals of orthoclase and quartz; the latter being minutely distributed in the ground mass, though much of it appears to be of secondary origin, filling cracks in the section. The whole mass has been much kaolinised, and is darkened by the presence of minute specks of ferrite. Indications of fluxion structure are observable in the neighbourhood of the isolated felspar crystals, but the rest of the ground mass has lost all trace of this structure. It seems reasonable to infer, therefore, that this example displays an extreme type of devitrification, and that possibly many of the quartz-felsites belonging to the Old Red Sandstone formation of Shetland may represent what originally were rhyolitic rocks, though all traces of the original structure have disappeared.

We have been favoured with the following note from Professor Renard, who has kindly examined the typical sections showing fluxion structure from Shetland:—"L'examen que j'en ai fait a porté sur deux points: 1. Je crois qu'il n'y a pas lieu de douter que les echantillons, spécialement les sections typifiques 2, 3, 5, 59, montrent avec beaucoup d'evidence une structure fluidale. 2. Je ne vois pas d'inconvenient a'nommer cette roche *rhyolite ancienne*, et je crois en effet comme vous, que c'est une rhyolite dont la base s'est devitrifiée, et que ne contient guère d'elément vitreux après les modifications auxquelles elle fut soumise. Si on admet cette manière de voir, d'après la classification que nous suivons sur le continent on la grouperait peut-être parmi les *felsit pechsteine*, mais c'est là un terme de nomenclature sur laquelle il y a beaucoup à distinguer. Vous savez, mieux que je ne puis vous le dire, que les *felsit pechsteine* représente les *rhyolites anciennes* et aprè tout l'un nom vaut l'autre."

On referring to the table of chemical analyses, it will be seen that the members of the acidic series—both the intrusive sheets and the branching

veins—are closely allied to each other in chemical composition. The granites of Rooeness and Sandsting, the spherulitic felsite of Papa Stour, and the rhyolites of Papa Little, yield similar results. The percentage of silica in the Sandsting granite is 70·96, in the Papa Stour felsite 69·12, in the grey and pink varieties of rhyolite 73·70 and 72·32 respectively. There is no appreciable difference in the other ingredients, save in the quantity of potash in the Papa Stour felsite, which amounts to 10·17 per cent. The specific gravity of the granites and rhyolites is 2·6, while that of the Papa Stour felsite is 2·5.

In conclusion, we might thus briefly summarise the results of these investigations.

1. The porphyrite and diabase lavas of Shetland belong to a basic series, and present microscopic characters akin to the great volcanic series of Lower Old Red Sandstone age in central Scotland.

2. The intrusive diabase dykes and bosses resemble the foregoing in chemical composition and microscopic characters, though they are separated from each other by a considerable interval of time.

3. The great intrusive sheets of Rooeness Hill and Sandsting consist of binary granite and ordinary micaceous granite respectively, while the Papa Stour sheet is composed of pink spherulitic felsite. The dykes of devitrified rhyolite, associated with the binary granites, closely resemble the granites and felsites in chemical composition, and hence the divergence in lithological and microscopic characters is due to the different conditions under which they consolidated.

4. The well-marked fluxion structure displayed by the rhyolites seems to indicate that they originally possessed a glassy ground mass, which has to a large extent disappeared through devitrification.

5. The mere presence of fluxion structure in igneous rocks does not by itself prove that the lavas were ejected at the surface, as the physical relations of the Shetland rhyolites clearly show that they are intrusive.

Note.—Our best thanks are due to Professor Renard and Mr T. Davies for the assistance they kindly rendered in the microscopic examination of these rocks.

CITY ANALYST'S LABORATORY,
138 BATH STREET, GLASGOW, 22*nd June* 1881.

ANALYSES of eight Specimens of Shetland Igneous Rocks received from J. HORNE, on the 4th February 1881.

	1. Porphyrite from Rooeness Voe, contemporaneous volcanic rock.	2a, 2b, 2c. Diabase between Clouster and Aith Voes, contemporaneous volcanic rock.	3a, 3b, 3c. Diabase, Skeld Hill, intrusive igneous rock.	4. Granitic Rock, Rooeness Voe, intrusive rock.	5. Granite from Junction of Old Red Sa., Gruting Voe, intrusive rock.	6. Spherulitic felsite, Papa Stour, intrusive rock.	7. Grey Var. Rhyolite, Papa Little, intrusive rock.	8. Pink Var. Rhyolite, Papa Little, intrusive rock.
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
Silica,	51·82	48·36	50·58	71·66	70·96	69·12	73·70	72·32
Alumina,	14·14	19·73	15·51	13·28	15·18	14·55	13·34	14·02
Peroxide of iron,	5·50	7·71	5·74	1·24	1·69	1·70	1·06	1·11
Protoxide of iron,	5·76	4·68	3·06	·10	absent	·14	·14	·47
Bisulphide of iron,	absent	absent	·45	absent	absent	absent	absent	absent
Oxide of manganese,	·25	trace	·29	absent	absent	absent	·10	trace
Lime,	6·10	6·63	9·52	2·24	1·52	1·57	2·33	1·14
Magnesia,	1·76	5·97	8·90	·64	·70	·52	1·24	·48
Potash,	7·81	2·57	·85	4·84	4·68	10·17	5·05	7·44
Soda,	1·09	3·47	2·89	5·37	4·32	1·27	2·43	2·53
Phosphoric acid (Anhydride)	·56	·05	·13	·18	trace	·05	trace	trace
Sulphuric acid,	·05	absent	·08	absent	·11	·12	·22	absent
Titanic acid,	absent	absent	absent	absent	absent	absent	absent	absent
Carbonic acid,	4·05	·10	1·28	absent	absent	absent	absent	absent
Water of combination,	·91	·53	·51	·30	·66	·67	·27	·40
Moisture,	·20	·20	·21	·15	·18	·12	·12	·09
	100·	100·	100·	100·	100·	100·	100·	100·
SPECIFIC GRAVITY,	2·743	2·788*	2·911*	2·609	2·618	2·540	2·652	2·621

* Mean specific gravity of three pieces.

ROBERT R. TATLOCK.

EXPLANATION OF PLATES XLV. AND XLVI.

Fig. 1. Porphyrite, Rooeness Voe, Northmavine, showing minute columnar crystals of plagioclase felspar, abundant magnetite, with a green decomposition product. A fine ground mass is interposed between the felspar crystals. This is a typical example of the porphyrite lavas of Old Red Sandstone age in Shetland (30 diameters).

Fig. 2. Diabase, Clouster Voe, Aithsting. A contemporaneous volcanic rock seen with polarised light. The crystals of plagioclase felspar are well preserved and abundant, the augite has been converted to a large extent into chlorite. Magnetite is very abundant throughout the section (70 diameters).

Fig. 3. Diabase, Skeld Hill, Sandsting. An intrusive rock seen with polarised light. This section shows the marked distinction between the interbedded and intrusive diabase rocks. The plagioclase felspar crystals are larger than in the preceding section, but much decomposed. The augite has been largely replaced by a green fibrous mineral, but fresh crystals are recognisable in the section. Magnetite is also present (20 diameters).

Fig. 4. Rhyolite, Papa Little. An intrusive rock showing dense bands of micro-felsitic matter, with a prism of orthoclase lying obliquely across the direction of the flow. This section exhibits very perfect fluxion structure, the movement being from right to left (20 diameters).

Fig. 5. Rhyolite, Papa Little. An intrusive rock seen between crossed Nicol prisms, showing wavy bands of micro-felsitic matter, which partly remain dark and partly transmit a faint light. Lines of quartz and felspar are arranged more or less parallel with the wavy bands of vitreous matter. The quartz is elongated in the direction of the flow (20 diameters).

Fig. 6. Spherulitic felsite, Papa Stour. An intrusive rock seen with polarised light, composed of reddish-brown felsitic matter, arranged in well-marked spherules, in which the fine radial fibres are prominently developed. In some parts of the section the diverging fibres have been supplanted by a fine grained ground mass. Nests or cavities filled with a secondary quartz are visible. The ground mass is stained with minute ferruginous particles (70 diameters).

Fig. 7. Felsite, Dales Voe, Sandness. An intrusive rock seen with polarised light, showing a fine felsitic ground mass, with large irregular grains of quartz containing fluid inclusions. Strings of quartz also traverse the section. A well-marked prism of orthoclase forms a prominent feature near the centre of the drawing, and minute grains of magnetite are evenly distributed through the mass (30 diameters).

Fig. 8. Binary granite or aplite, Heads of Grocken, Northmavine, seen with polarised light, consisting of reddish-brown orthoclase, which is much kaolinised, and quartz with fluid inclusions (20 diameters).

Fig. 1.

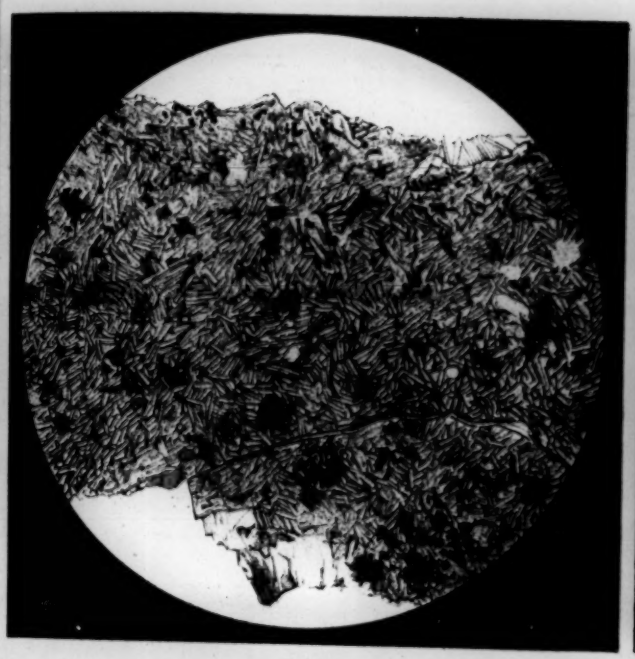


Fig. 2.



Fig 3.

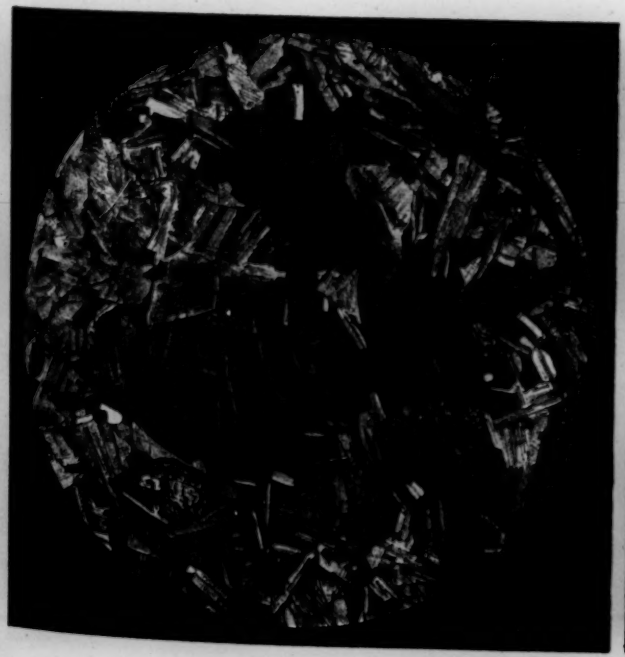


Fig 4



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Fig. 5.

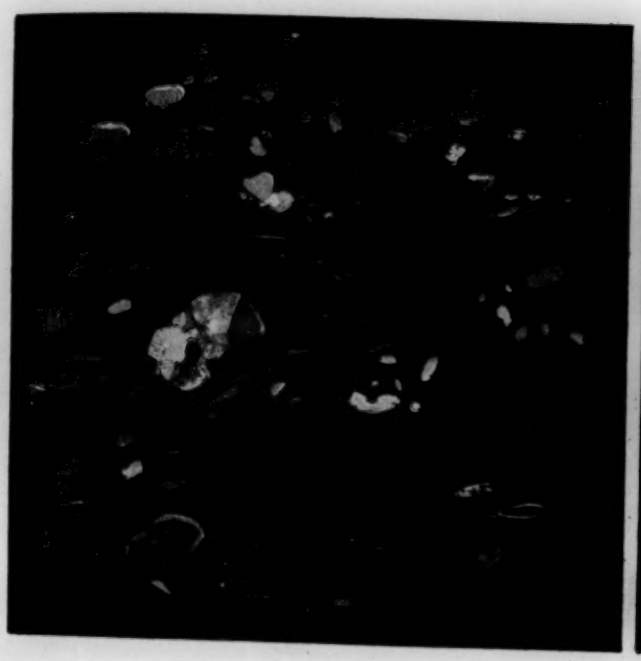


Fig. 6.



Fig. 7.



Fig. 8.



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XXII.—*Observations on a Green Sun and Associated Phenomena.* By Professor C. Michie Smith. (Plate XLVII.)

(Read July 7, 1884.)

The appearance of a green or blue sun, though not unknown, is of sufficiently rare occurrence to make a full investigation of all the phenomena connected with it highly desirable. I have therefore tried to obtain as accurate and complete information as possible concerning the appearance of a green sun in India during several days in September 1883.

The general features of the phenomena were well seen in Madras, and will probably be best described by my notes taken at the time. On September 9th the sun before setting assumed a peculiar silvery appearance, and its brightness was so much decreased that for about half an hour before sunset it could be observed with the naked eye. This was observed, I believe, though to a less extent, on the two days preceding, but I did not myself see it on these days. On September 10th, from 5.0 to 5.30 P.M., the sun could easily be looked at with the naked eye, yet the limbs were sharply defined. At 5.30 the sun entered a low bank of clouds, and did not fully reappear again, but a narrow strip seen through a rift in the cloud at 5.43 was coloured a bright pea green. Round Madras this colour had been seen in the morning, but in Madras itself clouds concealed the sun till it had risen to a considerable altitude. Of the morning of the 11th I have no record, but in the evening the green colour was very brilliant, and was visible for more than half an hour, being preceded, as on the former night, by the silvery white appearance of the sun's disc. On this evening a large sunspot about one foot long was so conspicuous an object that it attracted the attention of even the most casual observers.

September 12th, at 12.35 A.M., the moon, which was near the horizon, appeared a pale green. Bright stars near the horizon showed the same tint. From 5.15 to 5.30 the clouds to the east were coloured reddish-brown. At 5.55 the sun rose with a yellowish-green colour, but was almost instantly lost in clouds. It reappeared at 6.4, and was then of a bright green colour; this colour rapidly got fainter, but was quite perceptible till 7 o'clock. In the afternoon, the phenomena of the previous nights were repeated, and the horizon being free from clouds, the actual sunset was observed. The entry in my notes is—"6.3, the sunset as a greenish-yellow ball, cumulus, stratus, and nimbus clouds near the horizon, but moon fairly clear. Some blue sky, but hazy." The change from green to greenish-yellow was evidently due to the great increase in the strength of the

low-sun band close to the horizon, which left the strip of yellow between that band and the rain-band by far the most prominent feature in the spectrum.

September 13*th*.—In the early morning there was a good deal of distant lightning. The sun rose of a bright golden yellow colour; no green was seen. In the afternoon there were slight showers. A most remarkable observation made this morning by Mr Pogson seems very difficult to explain, except by some form of auroral display. I give his notes in full:—

"*September* 12, 1883, $17^h\ 0^m$, Madras mean time.—The sky a most remarkably intense reddish-yellow, so unusually bright that I called up my daughter Isis to witness it. A dark cloud bank from about east to south, and the vivid light above uncommonly auroral in appearance; more so than anything I have seen here before.

"At $17^h\ 10^m$, the red hue considerably diminished, and bright orange yellow the prevailing tint. The light quite bright enough to make notes by.

"At $17^h\ 20^m$, the dark blue-black stratum now from about north to east, and very near the horizon. Sky tolerably clear to about 20° altitude, but of a rich red tint, with bright yellow clouds above, beginning at about 30° and covering the east of the sky.

"At $17^h\ 30^m$, all changed within the last four or five minutes, and writing now difficult without a lamp. A thick dark red stratum over the sunrise point, and everywhere else a very greenish-yellow.

"At $17^h\ 40^m$, the low cloud stratum now sea-green. Light only enough to write by with difficulty.

"At $17^h\ 50^m$, sun rising a bright yellowish-white, and otherwise nothing extraordinary, all unusual tints having disappeared with the sunrise."

September 14*th*.—Before sunrise the clouds were blue and grey, with patches of red. Clouds of all sorts,—cirrus, nimbus, stratus, cumulus, and mare's tails. Two bright flashes of lightning about 5.30 A.M. In the evening there was a slight green tinge, and after sunset the sky was golden red till 6.50, while mercury seen through the red haze was twinkling strongly.

September 15*th*.—The sun rose golden. In the evening the sunset was very fine; in the west the colour was golden to orange yellow, in the east it was greenish; red clouds remained till 7.5; there were very brilliant red "rayons de crépuscule."

From *September* 15*th* to *September* 20*th* the sunrises and sunsets were very fine, with red and gold for more than half an hour before sunrise and after sunset.

September 21*st*.—Sunset normal.

September 22*nd*.—The sun rose as a yellow ball, and showed distinct greenish-yellow afterwards. From ten minutes before till sunset, the sun was greenish-yellow, but the sun was much brighter than on the 10th and 11th.

September 23*rd*.—The sun rose very green. At 5.37 P.M. the sun appeared

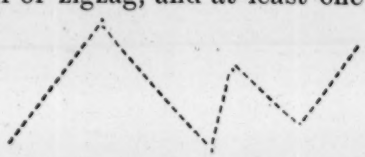
from under clouds very green. Strong absorption in the red end of the spectrum to C, low-sun bands weak. 5.45, clouds greyish-purple. There was only one bank of clouds which was near the horizon; above this was a peculiar greyish haze. At 6.0 the clouds were of a marked purple colour; breaks near the horizon were reddish-brown. During the night there was a great deal of sheet lightning in the south.

September 24*th.*—The sun rose bright yellow. The spectrum showed complete absorption up to B; the rain-band, α and β were very thick, and the low-sun bands less marked than usual. There was lightning all night, beginning in the south and working round to the south-east. It consisted chiefly of sheet lightning, with occasional zigzag flashes, but no thunder; the stars were fairly clear except near the horizon. Saturn and the moon, when near the horizon, were both very dim.

September 25*th.*—Sunrise golden green. In the afternoon the shadows cast on white paper were still quite pink, but the sunset was bright yellow.

September 26*th.*—Much the same as yesterday.

September 27*th.*—Before sunrise C, β, α, the rain-band and the dry-air band were very strong, but the dry-air band was less than half as dark as the rain-band. The sun rose golden red. The spectrum showed signs of clearing up; glimpses of A could now be obtained. After dark there was very bright lightning in the west—sheet lightning, with a good deal of zigzag, and at least one very fine specimen of a flash such as is obtained by discharging a Leyden jar through a spangled tube, the flash being broken up into a number of detached pieces. During the day there were slight local showers in parts of the town.



September 28*th.*—Spectrum still showed great absorption. Lightning at night.

September 29*th.*—Absorption still very strong. After dark there was a display of luminous clouds, specially towards the east. After 11 P.M. there was very heavy rain, with much lightning and some thunder.

September 30*th.*—Sunrise golden. The spectrum *on* the sun showed A clearly, and was very thick.

October 2*nd.*—In the morning from about seven to nine, there was a thunderstorm, in which the thunder was almost continuous for above an hour and a half; but though the storm was almost vertically overhead, hardly any lightning was visible. Apparently the discharges were chiefly from cloud to cloud, and the thick layers of heavy clouds overhead shut out the flashes. The thunder was followed by heavy rain. The official Meteorological Report contains the following reference to this storm—"The weather on the 2nd instant was decidedly remarkable; thunder in the morning; heavy rain at noon, exactly

three inches being recorded by 1 P.M., and continuing less heavily, but steadily till 10 P.M. The total rainfall for the day was 4·88 inches."

To complete the description of the phenomena, I will now quote from the accounts of some reliable observers in other parts of the Presidency. The following is from the diary of the superintendent of the lighthouse at Muttum, in the south of Madras, for September 1883 :—

"*6th*, *7th*, *8th*.—After sundown on these days there was a very peculiar saffron glare, which faded as it became dark. On 8th it was very marked.

"*9th* (*Sunday*).—This day, from about 4 P.M., the sun became perfectly green, and could be looked at without any inconvenience. The saffron glare after sunset seen. The green appearance of the sun continued several days, both in the morning and the evening.

"*13th*, 6.30 P.M.—A large meteor [? a fire-ball] passed from west to north-east. It burst three times and faded away.

"*15th*.—There were observed on this day five clusters of spots on the sun ; the green tint has been lost, and the sun is of a natural colour.

"*22nd*.—Sun again appeared of a very green colour, which continued every day up to the 28th."

The next account is from Bellary :—

"*Sunday*, *9th September*.—Sun set as usual, but after sunset a lurid glare spread over the sky, the colour being red with mauve in it. [Another correspondent writes that he thought the infantry lines were on fire.]

"*Monday*, *10th*.—Sun, both at rising and setting, emerald green.

"*Tuesday*, *11th*.—Again the same appearance both at rising and setting.

"*12th*, *13th*, *14th*.—Emerald green at sunset. After this week no record."

From Coonoor, on the Nilgiris, more than 6000 feet above sea-level, I have the following notes from Mr J. F. GELL :—

"Sunday week (9th) was remarkable chiefly for a persistent red glow, likened by many to the reflection of some great fire. Our sunsets have been gorgeous for several days, always abounding in the peculiar pea-green tints. Last evening (20th) the eastern sky and the whole landscape showed a most lovely and unusual greenish glow. After sunset a few clouds in the east were tinted lilac. The more distant mountains stood out very distinct against the green—clear but somewhat deep—of the sky. All near trees and other objects at hand had a 'scene-painty' (chromium oxide suggested) green tint. Red predominated in the western sky on the many clouds; but there was an intensely luminous area of hardly yellowish light near where the sun had set, which must have continued an hour. The 'shimmery' appearance of the sun, and the ease with which it could be looked at during Monday to Thursday, were remarked everywhere. There has been a good deal of bright lightning seen at some distance over the plains on many days."

This is particularly interesting on account of its close resemblance to the description so often given of scenes in hill countries just before heavy rain.

Mr MANLEY'S observations at Ongole, which is the farthest north point at which satisfactory observations seem to have been made, have already been published in *Nature*, and need not be repeated here.

The Spectrum.

The observations on the spectrum were made partly with a direct vision spectroscope, with a lens in front of the slit (HILGER'S rain-band spectroscope), but chiefly with my zodiacal light spectroscope, which has a single large dense glass prism and a collimator three feet long. The great length of the collimator permits the use of a very wide slit, which was found to be a great advantage in this case. The only means of recording the positions of the lines is by reference to a reflected scale; and since all the lenses of the instrument are quartz, the focus of the observing telescope, and consequently of the scale also, has to be changed for different parts of the spectrum. This was found very inconvenient when it was necessary to take a number of readings in different parts of the spectrum in rapid succession. The positions of the bands cannot be considered as strictly accurate, but they cannot be far wrong, as they were fixed by reference to known lines near them, and the scale values for the different parts of the spectrum were obtained by plotting the scale readings for known lines in terms of wave-lengths, and smoothing the curve. The main features of the spectrum taken *on* the sun when green were—

(1) A very strong general absorption in the red end.

(2) A great development of the "rain-band" and of all other lines which are ascribed to the presence of water vapour in the atmosphere, more especially of the group C_1 of α, and of the band at W.L. 504.

The absorption in the red end was of very varying intensity; but when the phenomenon was at its maximum phase it gradually crept up from about B till past C, as the sun sank towards the horizon. On the 12th, when the sun was within a few degrees of the horizon, the absorption was well marked up to W.L. 621—*i.e.*, to beyond α, while at the violet end the visible spectrum ended at W.L. 428, or just beyond G.

The lines A and *a* were never visible, even *on* the sun, when it was green, and even B could be made out with difficulty from half an hour before sunset onwards; and before it vanished it grew intensely prominent, with enormously thick bands on the less refrangible side. The band C, on the more refrangible side of C, became very broad and black, while the fine line between this and C remained thin and sharp, and C itself thickened out on the less refrangible side. The rain-band was stronger than I have ever before observed it on the plains;

and even with the dispersion produced by a single prism, at least eight lines could be measured in it, while many more were visible.

The low-sun band was not very conspicuous; but this was partly due to contrast with the very strong rain-band. The line W.L. 568 at the more refrangible side of the low-sun band was very well marked, and the band itself seemed to consist of a series of equidistant lines. The apparently much stronger absorption in the red than in the blue end was a very marked feature, which became still more conspicuous when a photograph of the blue end was examined.

A photograph was taken on the evening of the 23rd September, when the sun was very green, and the visible spectrum extended between W.L. 645 and W.L. 410. Half of the slit was exposed for twenty seconds, and the other half for thirty-three seconds. Both gave good photographs, extending from about F to a distance beyond H, twice as great as the distance between F and H. This is very nearly the same length as I obtain under similar circumstances in ordinary weather, though not nearly so long as I obtained last summer at an altitude of 6000 feet. The lines were sharp and well defined, and contained no bands that were specially prominent, though some seemed darker than usual. I have, unfortunately, no means at present of making an accurate determination of these lines. The atmospheric band C was very strongly marked, and was decidedly more conspicuous than C itself. It was thick and dark even at an altitude of 60° or 70° in the middle of the day, and formed then, next to the general absorption, the most characteristic feature of the spectrum. The contrast of the thin line between C and C′ with these lines was most interesting.

Since the passing away of the abnormal conditions, I have made careful observations of the sunset spectrum with the same apparatus, and I find that ordinarily A and a are clearly visible, as well as B, though at times they are strongly marked, and a good deal of shading is observable between them. C′ is much thinner, and the rain-band is less prominent than the low-sun band, which, however, does not now have the appearance of a number of fine lines. The nearest approach to the green sun spectrum was observed recently during a severe thunderstorm, which was accompanied by a fall of about $1\frac{1}{2}$ inch of rain.

A very similar though less intense spectrum can be observed almost any evening by taking advantage of the passage of a small thin cloud over the sun's disc. If a lens is used in front of the slit of the spectroscope, the absorption due to the cloud will be seen as a band in the middle of the bright spectrum from the unclouded part of the sun; and, owing to the strong contrast, the details of the absorption will be well seen, just as in the case of a spectrum of a sunset.

Meteorological.

My attention was first called to the peculiar state of the atmosphere on September 3rd, when making observations on atmospheric electricity. Observations made at 10 A.M. on August 31st showed a normal but rather low electrification; no observations were made on the 1st or 2nd September, the electrometer being out of order. On the 3rd, after the instrument had been carefully dried, observations were begun at 1.10 P.M., when the air potential was found to be negative, the electrometer readings varying from −28 to −17 divisions. By 2.45 it had become positive, amounting, however, to only +6, which was also the reading at 4.45. During the succeeding days numerous readings were taken, and these show a remarkable state of electrification (see Appendix A). The general results of the observations may be summed up thus:—In the early morning the potential of the air was positive; it continued positive, but gradually decreased in strength till some time between 9 and 10 A.M., when it fell to zero, and then became negative. The strength of the negative charge varied greatly and with remarkable rapidity, and the maximum readings were obtained either just before or during strong gusts of wind. The negative charge continued till the sea breeze set in in the afternoon, when it became positive, and continued so all night, and in all cases, I believe, the change of sign coincided with a change in the direction of the wind. Very high readings were at times obtained; in one case the reading was −459 divisions of the scale (=about 1900 Daniell cells or 2100 volts) at about 5 feet above the ground, in bright sunshine with a clear sky, but with a gusty wind, which raised clouds of dust. At other times there would be scarcely a trace of electricity perceptible. In all cases in which the potential was negative it decreased with height, but when it was positive it increased with height. Another point worth noticing is that, when negative, the potential might vary very much, but with two exceptions (and these are a little doubtful) it did not change sign, as one finds so often in a thunderstorm. This state of affairs continued from September 3rd to September 6th. On the 7th the potential was positive all day, the day being cool and cloudy throughout. On the 8th it was negative for a short time; on the 9th it was again positive all day; on the 10th, 11th, and 12th, it was as from the 3rd to the 6th; from the 13th to the 19th it was normal, though on the last of these days it fell to zero at 11 A.M. From the 20th to the 27th it was again abnormal,—positive till about 9.30 A.M., then negative and then positive again,—except on the 23rd, when the lowest reading obtained was zero. After the 27th the readings were all positive.

It will be observed that all the negative readings were obtained when the

wind was westerly, and after the day had so far advanced that the ground had begun to grow hot. This westerly wind is a hot land-wind, and on a previous occasion I obtained negative readings during its prevalence (*Proc. Roy. Soc. Edin.*, vol. ix. p. 615), but then there were local showers a few hours afterwards. Thinking at the time that this was probably a similar case, I wrote a note to the local papers on the 6th, asking particulars of the weather within a radius of 100 miles of Madras, especially with reference to rain, thunder, and lightning, and wind direction between the 1st and 6th of the month. In reply to this I got information from various stations which was of considerable interest, but apparently no rain fell within 100 miles of Madras up to the 6th, but on that day there were a few showers in and around Madras (0·03 inches at Madras Observatory). On the same day there was a storm at Tindivanum, about 75 miles south of Madras, which is thus described by a correspondent:—"At about 3 P.M. on the 6th a severe storm passed over this place, direction west by a little south to east by a little north. Wind preceded rain by a quarter of an hour, and blew steadily (not in gusts) for an hour; velocity not known, but must have been very great. . . . . Rain fell in torrents from 3.15 to 3.45, and from this time till 6 P.M. it continued to drizzle. There was only one clap of thunder, which lasted some two or three minutes, and seemed to roll on eastward; it took place about 3.30. This seemed to break the violence of the storm. . . . ." Of this storm, which seems to have been very violent and local, I received another account from a gentleman who passed through it in the train, and who stated that the storm was such as he had seldom, if ever, experienced before. From Canajore in Mysore I received the following:—". . . . . Here, 6 miles from the Western Ghauts, altitude 3100 feet, the weather during the first week of this month was abnormally wet. The average rainfall for September is about 12 inches, but between the 1st and the 9th I gauged 18·04 inches, the aggregate on the 6th, 7th, and 8th being 10·85 inches. No thunder." From the Koondahs, near Coonoor on the Nilgiris, another correspondent reports that he was awakened about 4 A.M. on the 9th by a terrific gale, which lasted for only about half an hour, and passed off as suddenly as it began. The reports show an abnormal state of the atmosphere, which tended to give rise to local disturbances. This abnormal condition is also shown in a report from Kodaikanal, on the Pulney Hills, kindly sent me by Mr LEVINGE, who has kept a rainfall register since 1873. He writes—"There was the same peculiar colour of the sun at rising and setting here which was noticed in other places, and on the same dates as recorded in the newspapers. The atmosphere here all the time was very hazy. The only other remarkable events were that we had frosts in the beginning of September, which I never observed before at that time of the year. The rainfall for September was also the lowest I have any record of; it was as follows:—1st to 13th, none; 14th, 0·40; 15th, 1·35;

19th, 0·40;—total, 2·15 inches. [Average for September, 6·65 inches on thirteen days.] During the month we had no thunder or lightning. Early in the month the wind was from the north, which was unusual." An examination of the daily weather reports for the month shows that in the earlier part the "general weather" to the north was threatening or overcast, in the central parts of the Presidency it was fine with passing clouds, and in the south sultry. From about the 7th onwards for some days there are frequent reports of "dust haze," "sultry," and "dark gloomy weather" in the reports; while, on the other hand, at two stations the report is, "atmosphere unusually clear."

The rainfall for September over the whole Presidency was much less than usual. The average for fifteen stations for which reliable data are available is 3·24 inches, instead of 6·90, the average for preceding years. The monsoon rainfall, on the other hand, was much above the average for the same fifteen stations. The rain at some stations continued into January, but taking only the months of October, November, and December, the average rainfall was 21·75 inches, while the average due for the same time is 17·36. This includes Bellary, at which the fall was 11·90 inches *below* the average.

The barometric variations during the month also seem worth a careful study. Except for Madras, I have only the 10 A.M. readings, but these may generally be taken as yielding a fairly accurate, though rather less smooth, barometric curve than that which would be obtained from the mean of the corrected three daily observations. The accompanying diagram shows the curves for Colombo, Madras, Belgaum, Allahabad, and Calcutta (Alipore). The first point that strikes one on examining the curves is their strong general resemblance, showing the same causes at work in producing change of pressure over the whole area of India. We have first a minimum, which was on the 6th at Colombo, Madras, and Allahabad, and on the 7th at Belgaum and Calcutta. The delay at these two last places was exceptional, for out of ninety-three stations sending in reports only thirteen show a falling barometer on the 7th, and these are connected with small local areas of depression. The rise to a maximum is rather irregular, but it is reached for most stations on the 18th, and the report for the 19th shows a fall at every station except Sholapur and Moulmein. The fall continued till the 21st, when a rise took place at the great majority of stations. A third minimum falls on the 27th. Observations made with the black bulb solar radiation thermometer *in vacuo* and the grass minimum thermometer will be referred to further on.

In any attempt to discover the cause of the phenomena observed it is of importance to determine exactly the dates at which they were first seen at different places. This, however, is a very difficult thing to do, inasmuch as most of those who have reported on the subject have been untrained in exact

observations, and in many cases have made more definite statements than their observations warranted. Thus, for example, I watched the sunset on the 9th, and certainly there was no trace of green in the silvery colour of the sun's disc; yet several people in Madras told me that they had seen the sun set green on that night; but this was after they had seen the green sunsets on the following nights. I believe this is only an illustration of what happened in many cases, the peculiar sunset on the evening of the 9th was observed casually, then when people began to talk about the green sunsets of the 10th and 11th, the casual observer recollected that he had seen something peculiar, and his imagination gave the silvery whiteness a green tinge. This has made me careful to sift as far as possible the various statements which I have received, and, though I cannot claim that the dates which I have accepted are in all cases absolutely accurate, I think that they come very near the truth.

The general result of my investigation into the dates of occurrence of the phenomenon is, that in Ceylon, in the south part of the Madras Presidency, and at Ongole, in the north, the sun first appeared green on the evening of the 9th, and that over the rest of the Presidency, where seen at all, it was first seen on the morning of the 10th. At Belgaum it is reported to have appeared on the 8th, and if this is accurate it is the earliest date on which it was seen anywhere in India, and would at once negative the idea of a gradual propagation either from south to north or from east to west. I have no good reason to doubt the accuracy of my Belgaum correspondent, but as no notes seem to have been taken at the time, it is possible that he is not strictly correct. Beyond India I have two reports from ships at sea—one from the captain of the "Cleomene," who reports that there was a green sun and moon on the 9th, 10th, and 11th, when his position was from lat. 8° N. to lat. 16° N., and from long. 83° 30′ E. to long. 88° 40′ E. In the same letter he reports that his ship was struck with lightning on the 1st. The other report is from the chief officer of the s.s. "Pelican," who has given me the following extract from his log:—"September 10th—The sun rose this morning looking quite green; never saw the like before. Last evening the sky had a greenish haze, making the moon look sickly pale green, and a few peculiar black clouds like wisps or mare's tails. Light breeze from S. to S.W. with high S.E. swell. Position at noon, lat. 10° 4′ N., long. 64° 12′ E. It was preceded by squally weather, with strong S.W. wind and *very damp* weather;—heavy dews at night." Thus at two places—Madras and the position of the "Pelican"—more than 1000 miles apart, the phenomenon appeared simultaneously, while to the south and east it appeared on the previous day. At Ongole, lat. 15° 30′ N., long. 80° 8′ E., Mr Mandey saw the green sun on the 10th, and was informed that it had been seen on the 9th by one whose evidence he thinks entirely satisfactory. I have no information to show that the green sun was seen at

any stations farther north except Vizagapatam, Rajamundry, and Simla, and unfortunately I cannot obtain the dates at which it was seen at these places. At Bombay it cannot have been at all conspicuous, for though noticed by some persons it was not seen at the Observatory, and so I cannot obtain any accurate details as to the date of first appearance, &c. Beyond India we have several dates which seem to be fixed with considerable certainty. In Honolulu, on September 5th, the sun's disc before setting was seen to be green (*Nature*, vol. xxix. p. 549). On September 4th, at 5 P.M., the master of the "Jennie Walker" "noticed the strange appearance of the sun, which was greenish." The ship's position then was long. 155° 28′ W., lat. 8° 20′ N. A passenger travelling from San Francisco to Sydney, three days out from Honolulu, writes:—"On Wednesday, September 5th, we witnessed a most curious phenomenon. The sun set perfectly blue, and next morning it rose a flaming ball of blue" (*Nature*, vol. xxix. p. 181). From Barinas, in Venezuela, we have a report that "on September 2nd, from daylight until noon, and from 3 P.M. to sundown, the sun appeared like a globe of burnished silver; between noon and 3 o'clock it was of a bluish-green colour" (*Nature*, vol. xxix. p. 77). At Trinidad, on September 2nd, the sun was observed as a blue globe at 5 o'clock (*Nature*, vol. xxviii. p. 577). It was seen at Panama on the 2nd and 3rd, and at Cape Coast Castle, apparently, on the 1st. All these dates refer to the first appearance, but we have a series referring to the second. Of these the earliest that I can find is in an extract from the log of the P. and O. s.s. "Nizam," with which Captain HARVEY has favoured me:—"September 20th, in lat. 12° 50′ N., long. 48° 26′ E., and the sun at the time being about 15° high, a greenish haze was noticed gathering over it and the sky generally in the west. As the sun decreased in altitude the green became more distinct, until a bank of green cloud, of various shades, formed on each side of the sun, and as the sun disappeared below the horizon so the cloud closed over the point of its setting. This peculiar sky lasted nearly an hour after sunset, and made a greenish twilight most wonderful to look at. The light air blowing at the time was from the eastward, and the weather fine and clear." On the 21st the same phenomena were observed, but not so clearly, owing to the ship's proximity to Socotra, "the wind at this time was S.S.W. and the air moist." The entry for the following day is also of interest. "September 22nd, in lat. 12° 00′ N., long. 58° 00′ E., the S.W. monsoon blowing fresh in this position and the sky cloudy, but there was unmistakably a greenish tinge in the west at sunset. From this date until September 25th the weather was overcast and cloudy, so that no observations were made; but in lat. 8° 50′ N., long. 71° E., the sun was again observed to set with a green tinge over it. The weather at this time was fine and clear, with a light northerly wind." At almost all stations in South India the greenness reappeared on the 22nd. Finally, we have the letter from

Hicks Pasha, dated Duem, September 24th—"To-day, when it [the sun] rose it was of a pale green colour." There is no proof, of course, that this is the date of its first appearance in the Soudan, but if the green was nearly as brilliant there as it was here, it could not have escaped observation.

Before discussing the causes of the phenomena that have been described, it will be well to point out that we must distinctly separate the green sun and the sunsets that appeared along with it from the remarkable sunsets which occurred nearly all over the world some time later, and which were visible here till at least the end of April. My reasons for making this separation are —1. The general appearance was quite different in the two cases. The sunsets accompanying the green sun were peculiarly lurid, and were, so far as I could judge, simply an exaggerated form of what we usually have some time before the bursting of the monsoon, and round the horizon we had then a most decided fog, in which stars were lost some time before setting. The main features of the subsequent sunsets, on the other hand, were the delicacy of the colours, and the beautiful rosy afterglow reflected apparently from very light cirrus clouds high up. The horizon at this time was remarkably clear, as is shown by the circumstance that Mr Pogson was able to make accurate measurements of the faint comet "Ross" within less than 5° of the horizon. 2. The spectrum was totally different in the two cases, for in the latter case the red end was very free from general absorption A, *a*, and B standing out clear and sharp, while the rain-band was slight, or altogether wanting, and the low-sun bands were strong—a complete contrast to what I have described as being visible in the former case. I may add, that any increase in the strength of the rain-band has been accompanied by a decrease in the brilliance of the afterglow.

To account for the green sun, three hypotheses have been put forward—

1. That it was due to vapours or dust from the volcanic eruption at Krakatao. First suggested by Mr Pogson.

2. That the cause was the presence of an abnormal amount of aqueous vapour. An explanation which I offered at the time of the occurrence.

3. That it was caused by a cloud of meteoric dust.

Mr Lockyer has taken up the first of these theories, and starting with the assumption that the sunset effects were due to the same cause as the green sun, has attempted to trace the general propagation of the dust round the earth. His first line passes through Mauritius, the Sechelles, Cape Coast Castle, Brazil, Trinidad, Panama, and Honolulu. His second is a line passing from south to north through India. Taking the dates of the appearance of the phenomena which can be relied on, we find that they would require approximately the following velocities of propagation—

Krakatao to	Mauritius, ...	161 miles per hour.
„	Cape Coast Castle, ...	71 „
„	Trinidad, ...	74 „
„	Near Honolulu, lat. 8° 21′ N., long. 155° 28′ E.,	85 „

These are the velocities if we assume that the column of dust was sent up by the great explosion which took place between 8 A.M. and 9 A.M. on the 27th; and even the plutonists seem to hesitate to affirm that the violence of the previous explosions was sufficient to send the dust up to the required height, though the first great shower of dust must have been ejected some time previous to that hour. When we consider that, from the nature of the case, the deduced velocities can only be very rough approximations, being in each case the minimum value, it must be admitted that the more distant ones agree fairly well with each other. Here, however, we are met by two difficulties, viz., is there any reason to believe in the existence of an upper current moving with anything like the requisite velocity? and, if it moved so fast along the one track, how was it so long of reaching Southern India? Regarding the first of these difficulties, it seems absolutely certain that no such uniformly strong currents exist, at least at any altitude to which the dust could possibly have been projected. Mr LOCKYER attempts to overcome the second difficulty by assuming an upper current from east to west, nearly along the equator. It crossed to the north however to reach Cape Coast Castle and Trinidad—and an under current from south to north. If, however, Mr MANLEY's observations are accurate, as there seems every reason to believe they are, it appeared at Ongole as soon as in Colombo, and at least twelve hours sooner than in Madras; and, if the Belgaum observations are accurate, it appeared there a day before it was seen in Colombo. Taking, however, only those observations about which there can be no doubt we get the following velocities, taking the shortest lines between Krakatao and the various stations:—

To Colombo, . . .	2000 miles,	6·7	miles per hour.
„ Madras, ...	2240 „	7·3	„
„ Bellary, ...	2450 „	7·9	„
Lat. 10° 4′ N., long. 64° 12′,	3100 „	9·8	„

velocities increasing with the distance from the source.

Taking these along with the Japan observations, which require a velocity of over 40 miles per hour, it seems very difficult to believe that dust would have travelled in these different directions with such very different velocities. Finally, we have the negative evidence, which in this case seems to have some weight, that the first rain which fell after the appearance of the green sun contained no volcanic dust. I collected several gallons of the rain which fell on the night of the 29th, and had the sediment which it contained carefully

examined under the microscope by Dr T. K. Rogers, a skilled chemist, but no trace of volcanic matter could be detected in it. I do not suppose that the asserted discovery of volcanic ejecta in rain and snow in Europe will be allowed to have much weight in the decision of the question, since, even if the volcanic nature of the materials found is proved, it still remains an open question where they came from.

With regard to the water vapour theory, there is at least some definite evidence upon which to found an argument. The spectroscopic evidence detailed above shows that all the prominent lines in the spectrum which are due to the presence of aqueous vapour were stronger than usual, and that there was, in addition, a strong general absorption in the red. This general absorption might doubtless be produced by the presence of dust of a suitable fineness suspended in the air, but that it may also be produced by water vapour, or at least by clouds, is amply proved by observations which I have since made on several occasions. In a recent thunderstorm, to which I have referred above, and which was predicted spectroscopically forty hours before it developed, I found almost exactly the same spectrum as in the case of the green sun, but the absorption in this case was produced by the passage of the sunlight through a comparatively thin stratum of dense cloud, instead of through a fairly transparent atmosphere. We know, too, that the absorption produced by aqueous vapour in certain conditions is capable of producing the observed appearance. On this point we have the observations made by Mr Lockyer, confirmed by other observers, of the sun being seen green through the steam escaping from the funnel of a steamboat, and his further observation of a green sun seen through a mist on the Simplon. We have also an observation made by Professor Piazzi Smyth (*Edinburgh Astronomical Observations*, vol. xiv. Appendix, p. 29), represented in a plate of which the following description is given:—"Two eye views of varieties of daylight, whereof the first represents a remarkable case of the sun looking *blue* rather than yellow, red, or the colours usually given to it by extra thickness of atmosphere; and the second shows a peculiarly green sunset sky—both of them proving to be forerunners of the sirocco's stifling wind and its concluding warm rain." The spectrum of the cloud light on this occasion shows a strong similarity to the spectrum observed here, only the absorption in the red end is less, and in the blue end rather more strongly marked. For my own part, I do not believe that a more or less green sunset is so rare an occurrence as has been supposed, and since my attention has been called to it, I have seen it several times and very markedly on the 13th and 14th of May, when it was perhaps the earliest symptom of the coming monsoon.

The abundance of water vapour present is also shown by the very heavy monsoon which followed the appearance under discussion, when in Madras

itself the rainfall was 19·17 inches, and in Masulipatam 15·71 inches above the average. We see then that aqueous vapour was present in large quantities, and that the presence of aqueous vapour is sufficient to account for the phenomena, so that it seems unscientific to call in the aid of any other agents, such as dust or sulphurous vapours, unless their actual presence can be proved, which, I submit, has not yet been done. Assuming then that the cause was aqueous vapour, the farther question arises, Why the phenomena should not be more frequently observed? This question cannot perhaps be fully answered at present, but some light can, I think, be thrown upon it by the following considerations:—In most cases, where we have an excessive amount of vapour present in the atmosphere, part at least is condensed into clouds, and these even when light, form a screen near the horizon which shuts out the sun at the time when the greenness would be observed. In the present case, on the other hand, the vapour was almost entirely uncondensed, only a very light haze being observed, and a few clouds low down on the horizon. The vapour was also at a greater height than usual, and was probably diffused through a great depth of the air; while in India, at least, the meteorological conditions near the surface of the ground prevented the formation of low clouds.

An interesting question arises as to whether electrical action may not have had something to do with this distribution of moisture. The observations already described, both those made with the electrometer and those made on lightning, show that the air was very highly charged with electricity. I am not prepared to lay much stress on the electrometer observations, however, until I have had an opportunity of investigating more fully the ordinary state of the atmosphere during the prevalence of west and south-west winds. The circumstance that the potential of the air was negative only when the wind was westerly, and even then only when the surface of the ground was hot, seems to indicate that the chief cause of the peculiar electrical state lay in the lower parts of the atmosphere. At the same time, it seems well to record these electrical observations along with the other meteorological ones. Even neglecting the electrometer observations, we have still various indications of an abnormal electrical state, for all the clouds that were formed about this time were evidently highly electrified, and the abundant displays of sheet lightning—which I ventured to say were not due to the reflection from distant storms—accompanied by occasional flashes of forked lightning, were indications of the great storm which burst on October 2nd, when the vapour had at length condensed into clouds. In this connection, it ought to be noticed that the storm of October 2nd was one in which the discharges took place almost entirely between cloud and cloud. I do not know that there is sufficient experimental data to show whether or not highly electrified vapour would be less ready to condense into clouds than non-electrified vapour, but it seems probable that

this would be the case. The experiments made by Dr OLIVER LODGE (*Nature*, vol. xxix. p. 612) seem quite insufficient to found any theory upon, inasmuch as they deal simply with the effect produced on a mass of very fine particles of water in an enclosed space by a highly electrified point.

The presence of abundance of vapour seems to be explained, naturally enough, by the setting in of the moist monsoon currents in the upper parts of the atmosphere; or at least by the conflict between the north-east and south-west monsoons, which was apparently begun by that time.* It is by no means impossible that the Krakatao eruption may have had some influence on the direction of these currents, for we have proof of the immense displacement of the air caused by the eruption in the barometric waves which were traced three times round the earth. Further, the ascent of a heated column of air and vapour over the volcano would tend to produce an area of low pressure round it, and thus to set up a cyclonic influx of air from other places, and it is quite possible that this influx is indicated in the oscillations of the barometer shown in the accompanying diagram, the sudden cessation of the cause of inflow after the eruptions ceased, causing a series of decreasing waves—direct and reflected. The eruption may also have had something to do with the electrical state of the air, for we know from observations made on the spot, that much electricity was generated by the eruption, and Professor PALMIERI'S observations show that the material ejected from Vesuvius is negatively electrified. A hypothesis connecting the phenomena with the eruption at Krakatao in this way would not be liable to the same difficulties regarding the velocity of propagation as one which involves the actual transport of dust, for the delay at one place relatively to another might be caused by the absence of a sufficient quantity of vapour. The theory which I have suggested would also account naturally for the second appearance of the green sun, the interval being due to one of the familiar lulls in the contest between the two monsoons. On the dust theory, it seems very difficult to account for this second appearance.

At one time I was inclined to think that the theory which made the phenomena depend on cosmic dust was an extremely probable one, and that the dust formed nuclei, about which the vapour condensed in the manner shown by Mr AITKEN. Various observations, however, seem to negative this. It seems hardly possible that vapour was condensed in any quantity, else the absorption of solar heat would have been considerable. Observations made with the black bulb thermometer *in vacuum* are not very satisfactory, yet when carefully made with the same instrument under similar circumstances, they have some value. The Madras observations show that the readings were above the average for the month, and that on the 23rd, one of the days of

* See Mr LEVINGE'S remarks, *ante*, p. 396, and the extract from the log of the "Nizam," p. 399.

maximum greenness, 160°·7 was reached. The mean for the month was 147°·3, against an average of 136°·5. The presence of either dust or condensed moisture in quantities sufficient to have produced the observed effect would, it seems certain, have intercepted the solar heat to a great extent, but vapour, on the other hand, probably would not. Admittedly the question of the absorption of radiant heat by aqueous vapour is still a moot one, but the recent experiments made by Professor M'Gregor, by Professor Tait's new method, show conclusively that the absorption cannot be nearly so great as many people have supposed; and we find such an experienced meteorologist as Mr Blanford stating, as the most probable conclusion from meteorological observations, that "both air and vapour, as compared with other gaseous bodies, are moderately good absorbers of heat, and in nearly equal degree."* The minimum temperatures, which are perhaps a safer guide to the transparency of the air, yield results similar to those of the black bulb thermometer; and observations of double stars showed that the atmosphere was clearer and steadier than usual. We must therefore, I think, give up any theory involving the presence of sufficient dust to render the sun green. Whether or not the following sunset glows were due to the presence of dust I cannot discuss here, but I would point out that an amount of dust sufficient to produce these effects would probably not materially affect the transparency of the atmosphere.

* *Indian Meteorologist's Vade Mecum*, part ii. p. 24.

[Appendix.

APPENDIX A.

Date.	Hour.	Wind.	Electrometer.		Remarks.
			Positive.	Neg.	
Sept. 3	1.10 P.	Lt. S × W.	...	28 to 17	
„	2.45	Do.	6	...	
Sept. 4	10.5 A.	Fr. S.W.	...	136 to 44	On roof.
„	10.10 to 10.17	Do.	...	299 460 425	Ground—wind in gusts with much dust flying; bright sun.
„	...	...	...	182	When wind light, R. B. 2.
„	Noon	Do.	...	67	Very fine and bright.
„	1.10 P.	Lt. S.W.	...	11	Ground.
„	3.0	Lt. E'ly.	35	...	Do.
„	6.30	...	5	...	Do.
Sept. 5	5.50 A.	Lt. W'ly.	5	...	Roof—clear.
„	9.0	Fr. S.W.	...	2	Ground—bright.
„	...	...	...	Trace.	Roof.
„	10.0	Do.	...	72	Do.
„	...	...	...	86 to 122	Ground—dust flying.
„	11.5	Do.	...	325 to 368	Wind gusty.
„	...	...	...	40	Calm.
„	1.5 P.	Lt. S.W.	...	20	
„	2.5	Do.	...	35	Cloudy.
„	2.10	...	...	1	Roof—wind going round to S.E.
„	3.15	Very light.	12	...	Ground.
„	5.0	Fr. S × E.	10	...	Cloudy.
„	6.20	Do.	29	...	12 feet above ground—thin clouds.
„	10.10	Light.	2	...	Do.—starry, with light clouds.
Sept. 6	6.0 A.	Light W.	5	...	
„	8.0	...	11	...	Do.—cloudy.
„	9.0	...	7	...	
„	9.45 A.	Lt. W. × S.	...	74	Ground—cloudy.
„	10.5 10.10	Do.	...	188 to 432	Do.—just before slight dust-cloud.
„	...	...	...	18	Steady.
„	1.10 P.	Do.	...	24	
„	2.5 to 2.10	Do.	6	67 45 125 106	From window about 40 feet high—dust-storm, and a few drops of rain, followed by heavy rain.
„	2.20	Lt. W'ly.	...	560	Roof—rain ceased. This was followed by one clap of thunder. R. B. 8.
„	4.20	S.W.	10	...	Roof—followed almost immediately by a shower.
„	6.15	Fr. S.	31	...	Steady—dry.

APPENDIX A.—*continued.*

Date.	Hour.	Wind.	Electrometer.		Remarks.
			Positive.	Neg.	
Sept. 7	6.0 A.	Mod. W.	25	...	Steady—cloudy and cool.
,,	9.0	Very light W. × S.	35	...	Do. do.
,,	10.0	Lt. do.	16	...	Do. do.
,,	11.30	Do.	15	...	Do. do.
,,	1.35	...	Trace.	...	
,,	2.45	S.W.	15	...	
Sept. 8	6 A.	Lt. W.	14	...	Roof—steady.
,,	9.0	Do.	11	...	Some clouds, but sun pretty bright. R. B. 5 to 6.
,,	10.0	Fresh.	...	6	
,,	11.0	...	...	Trace.	
,,	2.0 P.	...	5	...	
,,	4.20	...	146	...	Cloudy, apparent thunder cloud overhead.
,,	6.15	S. fresh.	38	...	Rain at 7 P.M.
Sept. 9	6.35 A.	Lt. W.	32	...	Cool and cloudy.
,,	8.10	Fresh.	16	...	Steady.
,,	9.0	Do.	14	...	R. B. 3 to 4.
,,	10.0	Do.	16	...	Thin clouds.
For the rest of the day maximum 16, minimum 13.					
Sept. 10	5.40 A.	Lt. W.	16	...	Cloudy.
,,	9.0	Do.	8	...	
,,	10.0	Very light.	...	21	Very little dust.
,,	11.30	Light.	...	46 to 10	Do.
,,	2.10 P.	Calm.	Trace.	...	Cloudy.
,,	5.10	Do.	...	31	Do.
,,	5.43	Do.	20	...	Thin clouds—very close and still.
,,	6.0	Do.	41	...	
Sept. 11	6.10 A.	Light W.	27	...	Steady.
,,	9.0	...	8	...	Roof.
,,	9.10	...	2	...	Ground.
,,	9.30	...	No	trace.	
,,	10.15 to 10.22	...	...	5 to 23	Cloudy, but hot.
,,	2.15 P.	...	13	...	Light clouds.
,,	10.20	...	9	...	
Sept. 12	12.35 A.	Lt. W.S.W.	10	...	Light haze.
,,	5.30	Lt. W.	18	...	
,,	6.30	...	23	...	R. B. 4 to 5.
,,	10.15 to 10.45	...	...	143 to 28	Ground—thin haze, and plenty of dust.
,,	...	...	...	4	Roof.
,,	3.50 P.	Lt. S.E.	42	...	
,,	5.30	Lt. E.	56	...	
Sept. 13	...	...	...	...	Positive all day. Max. 66 at 2.30 P.; min. 8 at 1.5 P.
,, 14	...	...	...	...	Do. Max. 60 at 5.45 A.M.; min. 11 at 9.40 A.
,, 17	...	...	...	...	Do. Max. 60 at 6 P.M.; min. 47 at 1.10 P. No observations in forenoon.
,, 18	...	...	...	...	Do. Max. 74 at 11.50 A.M.; min. 37 at 9 A.M. Cloudy.

APPENDIX A.—*continued.*

Date.	Hour.	Wind.	Electrometer.		Remarks.
			Positive.	Neg.	
Sept. 19	...	...	...	...	Positive all day. Max. 78 at 3 10 P.M.; min. trace at 11 A.M. Bright.
Sept. 20	6 A.	Light W.	63	...	
„	9.0	...	18	...	Light clouds. R. B. 5.
„	9.55	...	...	34	Cloudy.
„	11.55	Very Lt. E.	44	...	Clear.
Sept. 21	6 A.	Lt. W'ly.	29	...	Do.
„	9 A.	...	...	Trace.	
„	10.10 to 10.15	Very Lt. W.	9 to	19	
„	11.0	...	No	trace.	Hazy.
„	11.50	Light E.	19 to 34		
„	4.30 P.	...	42		
Sept. 22	8 A.	Light W.	No	trace.	
„	9.0	...	...	Trace.	Cloudy.
„	10.0	...	...	4	
„	11.0	...	No	trace.	Ground.
„	...	...	6	...	Roof.
„	...	...	4	...	At 12 feet above ground.
Sept. 23	...	...	...	...	Positive all day. Max. 11 at 3.30 P., min. 0 at 10.20 A.
Sept. 24	5.45	Light W.	35	...	Fine—slight mist.
„	9.0	...	15	...	Hazy.
„	9.50	...	...	25	Ground—bright.
„	...	...	...	8	Roof.
„	11.30	Light E.	25	...	Lightning all night to S. and S.E.
Sept. 25	7.15	Light W.	18	...	Cloudy and hazy.
„	9	Very Lt.	8	...	Hazy.
„	9.55	Light W.	...	33 to 8	Cloudy.
„	11.45	Light E.	27 to 50	...	Sun very hot.
„	4.40	...	22	...	
Sept. 26 „ 27	...	...	...	...	Slightly negative between 9 and 10, but positive at all other times. Thereafter no negative readings were got except in storms; but the readings have been low, except in stormy weather.

APPENDIX B.

Station.	Rainfall for October, November, and December.		Difference from Average.	
	Actual.	Average.	Above.	Below.
Vizagapatam,	19·40	20·13	...	0·73
Masulipatam,	28·12	12·41	15·71	...
Bellary,	5·47	17·37	...	11·90
Madras,	48·21	29·04	19·17	...
Salem,	19·48	10·17	9·31	...
Wellington,	25·11	18·98	6·13	...
Coimbatore,	15·73	9·92	5·81	...
Trichinopoly,	14·25	16·07	...	1·82
Negapatam,	32·48	31·27	1·21	...
Madura,	22·57	16·01	6·56	...
Cochin,	22·44	17·94	4·50	...
Mangalore,	8·47	10·50	...	2·03
Mercara,	17·21	10·58	6·63	...
Bangalore,	17·43	8·58	8·85	...
Colombo,	29·82	31·43	...	1·61
Average,	21·75	17·36	4·39	...

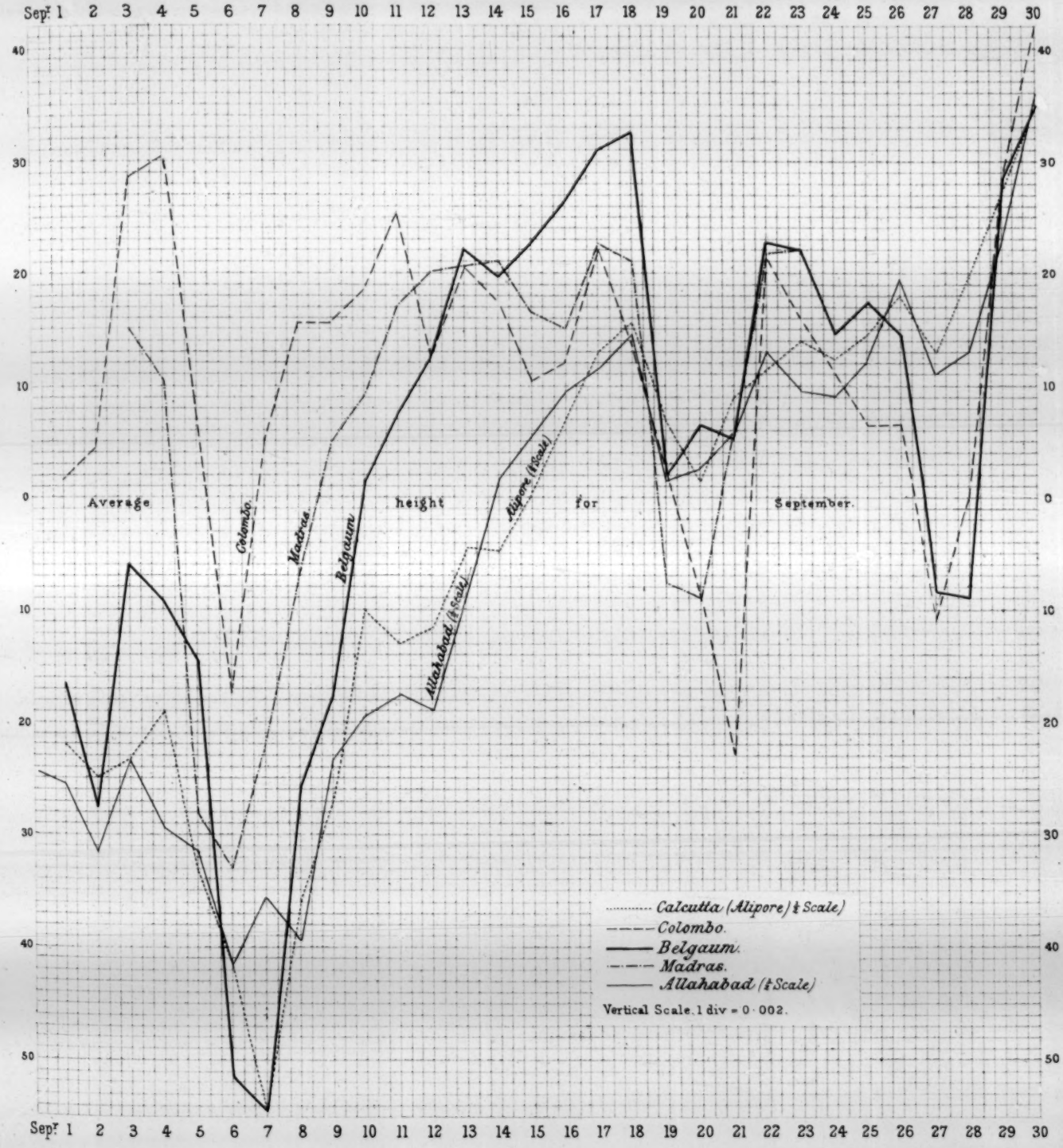
APPENDIX C.

Abstract of the Mean Meteorological Condition of Madras in September 1883, *compared with the Average of past Years.*

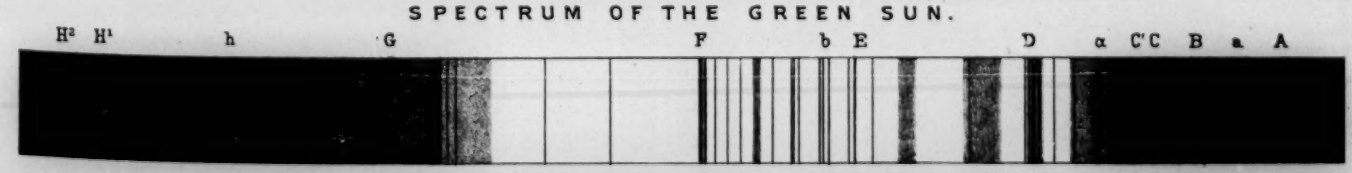
Mean Value of	1883.	Difference from	Average.
Reduced atmospheric pressure,	29·791	0·017 above.	29·774
Temperature of air,	84·7	1·6 do.	83·1
Do. of evaporation,	76·6	0·6 do.	76·0
Percentage of humidity,	68	5 below.	73
Greatest solar heat in vacuo,	147·3	10·8 above.	136·5
Maximum in shade,	95·9	3·8 do.	92·1
Minimum in shade,	77·9	0·6 do.	77·3
Do. on grass,	76·1	1·7 do.	74·4
Rainfall in inches on six days,	0·56	4·24 below.	4·80
Do. since January 1st on fifty-two days,	12·54	7·19 do.	19·73
General direction of wind,	S. by W.	2 points South.	S.W. by S.
Daily velocity in miles,	190	30 above.	160
Percentage of clear sky,	40	4 do.	36

N. R. POGSON, *Government Astronomer.*

BAROMETRIC CURVES. September 1883.



SPECTRUM OF THE GREEN SUN.



C. Michie Smith. del.

BRITISH
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XXIII.—*An Example of the Method of Deducing a Surface from a Plane Figure.*

By L. Cremona, LL.D. Edin., Hon. F.R.SS. Lond. and Edin., Professor of Mathematics in the University of Rome.

(Read 21st April 1884.)

Let there be given, in a plane π, six (fundamental) points **1**, **2**, **3**, **4**, **5**, **6**, of which neither any three lie in a right line, nor all in a conic; and consider the six conics $[1] \equiv \mathbf{23456}$, $[2] \equiv \mathbf{13456}$, $[3] \equiv \mathbf{12456}$, $[4] \equiv \mathbf{12356}$, $[5] \equiv \mathbf{12346}$, $[6] \equiv \mathbf{12345}$, and the fifteen right lines $\overline{\mathbf{12}}$, $\overline{\mathbf{13}}$, . . , $\overline{\mathbf{16}}$, $\overline{\mathbf{23}}$, . . , $\overline{\mathbf{56}}$.

There is a pencil of cubics $\mathbf{1^2 23456}$ (curves of the third order, having a node at **1** and passing through the other fundamental points); their tangents at the common node form an involution, viz., they are harmonically conjugate with regard to two fixed rays. Five pairs of conjugate rays of this involution are already known; for instance, the line $\overline{\mathbf{12}}$ and the conic $[2]$ have conjugate directions at the point **1**, for, they make up a cubic $\mathbf{1^2 23456}$.

Each other fundamental point is the centre of a like involution. And also on each conic $[1]$, $[2]$, . . . , and each line $\overline{\mathbf{12}}$, $\overline{\mathbf{13}}$, . . . points are coupled harmonically with regard to two fixed points. The involution on the conic $[1]$ is cut by the pencil of rays through **1**; for instance, the point **2** is conjugate to the second intersection of $[1]$ with $\overline{\mathbf{12}}$, &c. The involution on the line $\overline{\mathbf{12}}$ is cut by the pencil of conics **3456**; for instance, the points $\overline{\mathbf{12}} . \overline{\mathbf{34}}$, $\overline{\mathbf{12}} . \overline{\mathbf{56}}$ are conjugate, as $\overline{\mathbf{34}}$ and $\overline{\mathbf{56}}$ make up a conic through **3456**; and the point **1** is conjugate to the second meeting of $\overline{\mathbf{12}}$ with the conic $[2]$; &c.

The Jacobian of a linear twofold system (réseau) of cubics **123456** is a sextic $K \equiv (\mathbf{123456})^2$ having six nodes at the fundamental points. Since any réseau of cubics **123456** contains 1° a cubic $k \equiv \mathbf{1^2 23456}$; 2° a cubic breaking up into a ray r through **1** and the conic $[1]$; 3° a cubic made up by the line $\overline{\mathbf{12}}$ and a conic c through **3456**, &c.; we see immediately that the (sextic K) Jacobian of the réseau 1° has the same tangents as the cubic k at the common node **1**; 2° and 3° passes through the intersections of r with $[1]$, and the intersections of c with $\overline{\mathbf{12}}$, &c.

The Jacobians K form a linear threefold system of sextics $(\mathbf{123456})^2$

$$\lambda K + \lambda' K' + \lambda'' K'' + \lambda''' K''' = 0 ,$$

therefore we have the following theorem:

If six points **1**, **2**, **3**, **4**, **5**, **6** are given in a plane π, as said above, we may

construct a threefold linear system of sextics $K \equiv (\mathbf{123456})^2$, whose tangents at each of the six common nodes are coupled in involution, and which cut, also in involution, each of the six conics [1], [2], .. and of the fifteen right lines $\overline{\mathbf{12}}$, $\overline{\mathbf{13}}$, ... Any sextic of this system is the Jacobian of a réseau of cubics **123456**.

Among these ∞^3 cubics, there are ∞^1 curves possessing a cusp (stationary point), and the locus of the cusps is a curve $\Theta \equiv (\mathbf{123456})^4$ of the twelfth order, which touches each conic [1], [2], ... and each line $\overline{\mathbf{12}}$, $\overline{\mathbf{13}}$, ... in two distinct points, and has (only) two distinct tangents at each quadruple point **1**, **2**, ... : those points and these tangents being the double elements of the twenty-seven involutions mentioned above.

Let us start now from the foregoing plane diagram, without any further reference to its origin; and consider π as representative of a surface Φ whose plane sections shall have the sextics K as their images.* We see at once that the order of Φ is 12, for, two sextics K meet in $(6.6-6.4=)$ 12 more points. Thus we get a (1, 1) correspondence between the points of π and those of Φ; any point M on π being common to ∞^2 sextics K, it is the image of a point M′ on Φ, in which the ∞^2 corresponding planes meet. But if M lies on one of the six conics [1], [2], .. or of the fifteen lines $\overline{\mathbf{12}}$, $\overline{\mathbf{13}}$, .. or infinitely near to one of the six points **1**, **2**, ..., then all the ∞^2 sextics K passing through M contain also another common point M_1, which is conjugate to M in one of the twenty-seven involutions. Therefore, in such case, M′ is a double point on Φ: this surface has an infinite range of double points, whose locus, as easy to see, is constituted by twenty-seven right lines, having as their images on π the six fundamental points and the six conics and fifteen lines connecting them.

If M falls at the intersection of $\overline{\mathbf{12}}$, $\overline{\mathbf{34}}$ viz., if it belongs to two involutions, it will have two conjugate points $M_1 \equiv (\overline{\mathbf{12}})\,(\overline{\mathbf{56}})$, $M_2 \equiv (\overline{\mathbf{34}})\,(\overline{\mathbf{56}})$; and the three points M M_1 M_2 will be common to ∞^2 sextics K corresponding to ∞^2 planes, whose point of intersection M′ (where the nodal lines of Φ meet, which answer to $\overline{\mathbf{12}}$, $\overline{\mathbf{34}}$, $\overline{\mathbf{56}}$) is consequently a treble point on Φ. Thus, our surface possesses forty-five treble points, in each of which three nodal lines meet.

Let a cubic **123456** have a cusp M; then, every sextic $(\mathbf{123456})^2$, which is the Jacobian of a réseau including that cubic, shall pass through M and touch there the tangent at the cusp. Hence the ∞^2 sextics K through M will have the same tangent at this point. Accordingly the corresponding point M′ will be a double point on Φ with coinciding tangent planes, viz., a cuspidal or stationary point. Thus we see that Φ has a cuspidal curve, whose image on π is the locus of cusps of cubics **123456**, viz., the curve $\Theta \equiv (\mathbf{123456})^4$ of the twelfth order. The order of the cuspidal curve on Φ is $(6.12-6.2.4=)$ 24.

* See CAPORALI's paper in *Collectanea Math. in memoriam D. Chelini.*

The class of Φ, that is to say, the number of the tangent planes drawn through two arbitrary points in space, is equal to that of the intersections of the Jacobians of two linear twofold systems of sextics K. The Jacobian of such a system is of the order $3(6-1)=15$, and passes $3.2-1=5$ times through each fundamental point; but the curve Θ is clearly included in the Jacobian, therefore, this latter will break up into a fixed curve, Θ, and a variable one, being of the order $15-12=3$, and possessing the multiplicity $5-4=1$ at the fundamental points. So the residual Jacobian is a cubic curve **123456**. Two such curves meet in $9-6=3$ more points; hence the class of Φ is 3.

The surface Φ, being of the twelfth order and third class, and having twenty-seven nodal right lines and a cuspidal curve of the twenty-fourth degree, is the reciprocal of the general cubic surface. It was very easy to foresee this conclusion, in accordance with the (1, 1) correspondence between any surface and its reciprocal. But I wished to give an instance of the method of deducing a (unicursal) surface from a plane figure assumed as its representative.

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XXIV.—*Micrometrical Measures of Gaseous Spectra under High Dispersion.*

By C. Piazzi Smyth, F.R.S.E., and Astronomer-Royal for Scotland.

(Plates XLVIII. to LXXVIII.)

(Read 16th June 1884.)

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INTRODUCTION.

After the Royal Society, Edinburgh, had been pleased in 1880 to accept and print my paper on the general appearance of Gaseous spectra as seen on a very small scale, but complete on that scale from one end to the other of the visible spectrum, I was desirous to present them with some very highly Dispersed and much magnified views of the more interesting and probably crucial portions of the most important of those spectra.

An example of acting on that principle had already been set in the admirable essay of MM. ANGSTROM and THALEN, published in the *Upsala Transactions* for 1875. For there, both in the Plates and letterpress, the final portions entitled "Mesures Micométriques" are very largely magnified representations of certain small parts of what went before.

But just as occurred in the earlier division of that great work, so also in this later portion of it, there appeared to me to be too few gases, and too few portions of their spectra treated of, to supply a sufficiently comprehensive basis for this branch of science.

Neither again in their *Mesures Micrométriques* did the Dispersion power which those eminent philosophers employed, appear sufficient either in amount

or definition to bring out many of the exquisite and close-set details which spectroscopy is beginning to demand in the present day for any and every gas that is now observed. And this, too, although those Upsala results did most honourably transcend all others at the time they were published, and for many years afterwards, indeed almost, if not quite, up to the present time.

Hence I have felt it incumbent on myself, before venturing to trouble this Society with new versions of any old phenomena, not only to increase the range of subjects treated of, but to improve the instrumental apparatus employed on all of them, until it was capable of some very remarkable performances in the way at least of differential mensurations in the field of view or near it.

Of such differences, however, only. For temperature changes in the fluid prisms, although greatly reduced by a variety of contrivances, were yet continually at work, altering to so sensible an extent the value of the Dispersion scale from its distant zero, as to prevent the absolute places given by this very lately put-together apparatus being anything better than extremely rough when over long ranges.*

But condoning that one weakness, for the sake of other advantages, the strength of the instrument for micrometrical detection and record of small differences may be indicated thus—

(A) The one-prism spectroscope employed in my collective and rudimentary paper of 1880, possessed a little more than 3° of Dispersion from A to H, with a magnifying power on the telescope of 10 diameters; virtually broadening those 3° to 30°.

(B) The apparatus employed by MM. Angstrom and Thalen for their *Mesures Micrométriques*, as nearly as I can gather in a general way, must have had at the utmost a Dispersion A to H of 24°, with a magnifying power of nearly the same number of diameters; or equivalent virtually to a spectrum 600° long.

(C) While my present arrangement has 60° of Dispersion A to H, with magnifying powers on the telescope of inspection rising from 12 to 36, and a further mechanical magnifying in the recording apparatus of 5 times; equivalent to 9000 of the same degrees altogether; or to the action of 1800 simple prisms of 60° refracting angle in white flint-glass, viewed with the naked eye.†

* By observations on Green CO on November 3, 4, and 5, it was ascertained that, after everything had been done at the place that could well be done to secure constancy of temperature in the bisulphide of carbon prisms employed, a slow fall of 1° Fahr. increased the Dispersive power of the collective train of prisms by 0·727 of a Revolution of the very coarse screw motion; or by close upon 10 inches on the surface of the recording barrel. The interval of time therefore between any two mutually dependent observations was, after that, made as short as possible.

† The diameter of the objectives was the same as in my earlier apparatus, viz., 2·25 inches, and the refracting faces of the prisms presented nearly the same breadth to the entering ray.

To which qualities were added, when assisted however by certain more intense illuminations, a transparency nearly as great, and a definition in certain parts of the spectrum considerably better, than I have seen in almost any smaller instrument.

For this latter excellence I have chiefly to thank Mr ADAM HILGER, and to laud the extreme skill and perfection wherewith he constructed both the glass cores of the bisulphide prisms, and their all-important anti-prisms out of admirably hard, white, and uniform crown glass. The Micrometrical recording apparatus was exquisitely constructed by Messrs T. COOKE & SONS of York, to whom I am therefore much obliged; while I am further quite unspeakably indebted to the progress of Chemical Science, which has, in recent years entirely freed bisulphide of carbon from the horrors of its ancient smell, and has given us a fluid perfectly colourless, nearly inodorous, exceedingly transparent, and endued with less refraction but more concomitant Dispersion, than anything else under the Sun.

In discussing therefore the results obtained with all these advantages, I shall not only refer to MM. ANGSTROM and THALEN'S now nine year old, yet still most excellent, essay, but shall consider it a duty to seek out later and more advanced works, if they exist, elsewhere. Paying particular attention to the recent Reports of the British Association's very powerfully constituted Committee * for reporting on our present knowledge of Spectrum Analysis in 1880, 1881, 1882, and 1883.

For their admirable digests of all that has gone before, and all that has come up to their own time, in the now voluminous bibliography of the spectrum, enables every one to locate the place, and assign the value of any new observation both with high certainty and the least loss of time.

PART I.

THE FIRST GAS TO BE EXAMINED, AND UNDER WHAT CONDITIONS.

As my object has been to a large extent to pass over superficial variations, and arrive, if possible, at the great constants of Nature in this department,—

* The Members of the Committee are given thus—

Professor DEWAR.
Dr WILLIAMSON.
Dr MARSHALL WATTS.
Capt. W. DE W. ABNEY, R.E.
Mr STONEY.
Professor HARTLEY.
Professor M'LEOD.
Professor CAREY FOSTER.
Professor A. K. HUNTINGTON.
Professor EMERSON REYNOLDS.
Professor REINOLD.
Professor LIVEING.
Lord RAYLEIGH.
Dr SCHUSTER, and
Mr W. CHANDLER ROBERTS, *Secretary*.

it would seem that I ought to begin with the simple, elementary gases; and afterwards touch on their compounds if desired.

But the practical methods of inductive inquiry into Nature, oblige me to proceed in exactly the opposite manner, and begin, as did also the great Upsala leaders, with the manufactured compound gas most immediately at hand in any and every situation in life, viz., illuminating gas, whether of coal, oil, wax, or tallow.

There may be, as we shall see presently, some difficulty in deciding on the chemical interpretation to be put on the spectrum thence obtained, but there is none in procuring a view of it; for whether we observe the blue flame of a blow-pipe of coal-gas and air, or the blue base of an upright flame of either those or any other of the ordinary illuminants of night employed by man, burning in the open air,—there appears to be always the same identical spectrum present, differing in no one case from another, except in degree of brilliancy.

Were we to burn the illuminant in a current of pure oxygen, something additional might be seen. But I have purposely refrained from doing that, and confined myself, in this part of the inquiry, to the grand aerial constant for all men, compound though it be, of the earth's atmosphere, for the sole elementary aid to combustion, as a mode of obtaining incandescent temperature.

To make the effects of that, however, more visible than usual, I have employed a blow-pipe nearly a foot long; with coal-gas in quantity from the service pipes of the house, but urged in intensity by air from a bag under pressure equivalent to 6 or 8 inches of water: and have further always placed the flame thence procured "end-on" to the spectroscope's slit, in the manner described to, and approved by, the Royal Scottish Society of Arts several years ago. Thence results what the Brittish Association calls,

The Candle-Spectrum, in Air,

or, as named here, for reasons presently to appear, CH, *i.e.*, Carbo-Hydrogen, in Blow-Pipe Flame.

Having been introduced to this Society nearly thirty years ago, by our respected Fellow, Professor Swan, this particular spectrum will doubtless be well known to every one present, as offering a charmingly simple arrangement of five bands, most aptly to be compared to the human hand. For the first of them, orange coloured, and therefore in the orange region of the spectrum, is comparatively thin and weak, say like the little finger. The second, citron coloured, much stronger like the next finger. The third in the green, the brightest and strongest of the whole, like the middle finger. The fourth, in the blue, intermediate for strength between the first and second, like the index

finger; while the fifth, in the violet, is not of the build of any of the other bands; you may say not a finger at all, but shorter, broader, sturdier, like the thumb.

Viewed in any ordinary single-prism spectroscope, each of the first four of these bands begins on the red side with a strong line, followed by two, three or more similar lines, but in decreasing brightness and lessening distance, interspersed with haze; while the fifth band seems to be composed of nothing but haze.

This luminous hazy mist has, however, been occasionally seen by some individuals with powerful spectroscopes to be more or less resolvable into faint and exceedingly close lines or linelets. And now, with my new spectroscope, I have not only seen it *all* so resolved, but have been able to measure almost every linelet by micrometer, until at last they became too faint to be distinguished in any manner whatever.

The record thus procured, proving so neatly that there is no waste, neglected, unordered or accidental material in the spectrum of this cheapest of all the gases, was obtained on the instrument in so very magnified a condition, that the whole visible spectrum, or from red to violet on the same scale, would extend to 120 feet in length.

But this being supposed a rather longer scale than the world is as yet quite ready for, though demanding far more for certain parts of the Solar Spectrum, the original record has been reduced on subsequent working sheets to a 40 foot spectrum length. And as only the portions with very visible lines and linelets for the five bands of CH in air, are given,—this particular subject will yet be found in larger and fuller representation than it has probably ever enjoyed before, though packed away in four only of our plates.

The Spectrum Plates Employed here, their Methods and Symbolism.

For the original observations and records on both the long 120 foot scale, and the first reduction to the forty-foot, I am answerable myself. But the drawing out of the final and finished plates, thirty-one in number for the whole paper, and all save three on the same exact 40 foot Wave-number per British inch scale, has been confided to Mr Thomas Heath, First Assistant in the Observatory; because his handling of the pen and pencil is finer than mine; and, under photo-lithographic treatment will give something like the perfection of copper-plate engraving, without its superior expense.

The said plates are intended moreover to serve more than the usual purpose of such data. For though it is customary, and was actually done by Messrs Angstrom and Thalen in their classical case, to give both a printed list of the numbers representing their micrometrical measures, and also an engraved, and

most beautifully engraved, map, or picture of the same—yet I have invariably found a mere list of printed numerical spectrum places, by whomsoever issued, to be but very little instructive,—without spending a lamentable amount of time over its interpretation, application and meaning on every occasion of using it; while it is also not a little expensive to print. Hence I have tried on this occasion to save the cost of figure printing, by throwing the whole burden of what is needed for final results, on the Plates alone.

Spectroscopic plates of some kind, on account of peculiar virtues of their own for such subjects, *must* be introduced in some shape, or to some degree. The following characteristic sentence occurs in a British Association Report for 1883, p. 123:—"Three such spectra have been photographed, *but without the aid of maps their peculiarities are not capable of description.*" Wherefore now, by keeping our plates sufficiently large, and with very clear and distinct scales, we may hope that they will not only preserve their own peculiar attribute of showing at a single glance the groupings and general bearings of multitudes of lines far better than any other known method,—but they will allow, on close examination and longer inquiry, the numerical places of any particular lines to be read off to nearly as minute a degree of exactitude, as the original observations were capable of giving.

This good quality would have been absolutely so with the 120 foot records; and if not quite so with the 40 foot size, that is why I specially request that Mr HEATH'S drawings shall not be reduced any further, as no smaller scale can pretend either to do justice to the originals, see especially Plates LXXII. and LXXIII., or impart confidence to those who may use them. To which apology I have only now to add, that the following principles of representation have been strictly followed throughout all the plates of this series.

PRINCIPLES OF SPECTRUM REPRESENTATION.

Rule 1. The representation is negative, in so far as it shows light by black; and darkness by white.

Rule 2. A vertical black line, whether thick or thin, tall or short, on the plate, represents, and is devoted to representing, nothing else than a true spectral line of light, seen and measured as such in the spectroscope, and is considered as precious a result of observation or discovery to the spectroscopist, as a real star is to the Astronomer.

Rule 3. Different degrees of *brightness* in the real lines of light in these gaseous spectra, where all lines are necessarily of an equal height,—are represented in the drawings, *approximately* by different thicknesses of the black lines employed there; and more *exactly*, by adding thereto the further method of different heights or depths of the lines so drawn.

Rule 4. When lines of light in the spectrum are so faint or ill-defined that they no longer give the appearance of solid or liquid light, and are no longer sharp and smooth-edged like knife blades, or stretched silver wires, but look more like faint, uncertain, granular, worsted threads,—the lines representing them on the plates are not drawn in full ink or with parallel sides, but of a conical shape, or in dots, or in wavy lines, and in extreme cases with cross lines.

Rule 5. Faint broad bands in the spectrum, and its occasional portions of continuous spectrum light, are never indicated in these drawings by any kind or arrangement or succession of vertical lines, but by either horizontal, or oblique lines; and these may be crossed over and over again to produce the required degree of intensity in any case. For the lines of such shadings can evidently be never confounded with true spectral lines; which, being images of the slit of the spectroscope, must all be vertical and parallel, when the spectrum range is horizontal.

Rule 6. Shading by either inclined or horizontal lines being symbolic and abstract only; such lines may, for facility of execution, be of almost any degree of coarseness or width apart; provided only that the amount of ink contained in them shall, if symbolically supposed to be smeared up and down within the upper and lower limits of the horizontal spectrum strip,—indicate only a grey shade, not a full degree of blackness. And exceeding refinements of such shade or faint-light surfaces in the spectrum itself, may be indicated on the drawings by making the shading lines there cover more or less of height or depth in the spectrum strip, as already adopted for the easier representation of different degrees of brightness in the spectral *lines* alluded to under Rule 3.

Drawings of the CH Spectrum in Blow-pipe Flame.

Now all the latter of these rules came into play at once with our first subject, or the blue-grey blow-pipe flame of coal-gas and air; for there is not light enough in it to give off any lines of real, liquid light, only haze of different degrees of rarefaction.

Considering indeed the proverbial faintness of the blue base of flame, as when a candle burns low and blue, it is rather surprising to find that so very small a portion of it as enters between the almost closed jaws of the spectroscope's slit, can yet be distinguished as made up into upwards of 400 parcels, separated one from the other always by different and definite spectrum place; and sometimes also by instantly recognisable features of physiognomy or gradated intensity.

Yet such is the case, for the plates now exhibited of the coal-gas and air blow-pipe spectrum (Plates XLVIII. to LI.), show 81 separate existences in the

Orange band, 94 in the Citron, 97 in the Green, 107 in the Blue, and 71 in the Violet. Their distribution in each band appearing thus—

Orange band—	1st leader consists of lines	2,	followed by linelets	27
	2nd „	2,	„	14
	3rd „	2,	„	11
	4th „	2,	„	7
	5th „	2,	„	5
	6th „	1?,	„	6?
Citron band—	1st „	2,	„	25
	2nd „	2,	„	12
	3rd „	2,	„	9
	4th „	2,	„	7
	5th „	2,	„	31?
Green band—	1st leader, "Green giant"	2,	„	41
	2nd lines consists of	2,	„	11
	3rd „	2,	„	7
	4th „	1?,	„	7
	5th „	2?,	„	4
	6th „	1?,	„	17
Blue band—	1st „	2,	„	21
	2nd „	2,	„	14
	3rd „	2,	„	12
	4th „	2?,	„	5
	5th „	2?,	„	55
Violet band—	Preliminary band has linelets			20
	Subsequent and chief band contains lines and linelets of various kinds, certainly and probably many more; each being fainter and fainter in every successive repetition beyond.			51;

This is also probably the case with the linelets of the more refrangible ends of each of the earlier bands, for they are all vanishing series to that side. Hence to record more, or fewer of them, tells nothing new in the theory, but speaks only to the brightness of the optical images; and as I usually stopped, not when a definite end was arrived at, but when the linelets had become so faint and diffuse that it did not seem worth while to go on any longer,—other persons may succeed with better apparatus in chronicling more lines and linelets than I have done;—such gatherings however being always fainter than those now tabulated.

But even with them, the strain on the eye to measure their places micrometrically was often so great, that I was not unfrequently afraid I might be deceiving myself, and undoubtedly must have made many mistakes, particularly in setting the pointer between the close linelets, instead of upon one or other of them. Yet after completing the measurement of any band, there was found on the whole such a decided order, or law of increasing distance from linelet to

linelet, in proceeding from the red to the violet end, and of decreasing distance at the same time between the leading lines, or rather pairs of lines in each band,—as could not have arisen from mere accidental error, or blind fancy; and did seem to testify to a considerable portion of the interesting arrangements of Nature, in this branch of her handiworks, having been secured on this occasion in linear record.

If the leading lines too in each band, notwithstanding their faintness and haziness, have been represented by me as double, though single to all former observers, we may find strong confirmations thereof in our next subject, viz.,

Advantages of Electric-Lighted Gas Vacuum Tubes.

These tubes are usually illumined for observation by that variety of electricity contained in the spark from an Induction coil, actuated by a Bichromate Galvanic battery. Such was the kind employed here, and was capable of giving sparks from 2 to 4 inches long in the open air: the size of the immersed portions of the plates being 4″·2 by 4″·6; and the number of cells 12, but only 6 of them having fresh exciting fluid each observing night. The coil was by Mr Apps, said to be a 6 inch spark coil if used with five quart-sized Bunsen, or Grove, cells. It was also furnished with a quantity, as well as an intensity, primary; one or other to be employed alternatively; but after many trials with little or no difference on spectra, I settled down to the intensity arrangement alone, and to carefully attending to the state of the spring brake; its freedom from oxidation; or from becoming self-soldered, and being in the best state of strain for illuminating sparks, without stopping dead.

Employing these sparks then on vacuum tubes, they may of course be expected to show higher temperature effects than mere blow-pipe flame. But they have other advantages over both that method of incandescence, and induction electric sparks in the open air, whether taken direct from the coil or with the interposition of a condenser, in the shape of "the jar discharge."

To illustrate the nature of these advantages for our particular purpose of Micrometrical measures of precision, I submit on Plate LII. four views of the salt lines (D^1 and D^2 of the Solar spectrum) rendered incandescent in as many different modes, and viewed under high dispersion.

No. 1 is the effect of burning a solution of Na (chloride of Sodium) on a small spiral of iron wire in the flame of a Bunsen burner of coal-gas and air, in the usual manner of all ordinary Spectroscopists. The effect will be seen to be broad, dull and hazy in the extreme; there is much continuous spectrum paling the lines, and the outer envelopes of vapour of the flame produce on each line an inversion of the direct action; or cause a black line to run down

the middle of each big bright line,—represented here by a white line on a broad black band, splitting it into two, but foggily and uncertainly.

This whole result is of course most unsatisfactory and untoward to sharp, micrometric bisection.

No. 2 exhibits the spark drawn from a solution of Na forming one of the poles, the other being a platinum wire. There is here no continuous spectrum, there is also something sharper and more intense than before in the picture which it gives of the D lines; but the abnormal central line down the middle of each standard line is repeated; and the whole is in a peculiar, crackly, continually exploding, condition, also opposed to very nice bisection.

No. 3 shows the same identical spark, but altered in quality by the introduction of a half gallon Leyden jar. The change is immense, the whole field being now filled with fervid light of the general air glow, also with certain hazy air-bands palpitating in their heated atmosphere, and which I have not attempted to show, while the D lines are still split through the middle and are hazy both inside and out. Finally,

No. 4 shows the D lines in an end-on vacuum tube. The field here is absolutely black about them; the D lines absolutely bright, sharp, compact, steady, well defined, and everything that a micrometrical observer could desire.

In a second tube with the D lines still as above, there were a few faint, low temperature, Hydrogen lines. These were just as sharp and steady as the Na lines, but being vastly fainter were exceedingly thin; so that, overlooking linear, in place of disc-point, figures, the whole field of view gave one the impression of gazing upward into illimitable stellar space, where one star differeth from another in glory, but all of them exist in the quietude of heaven, the calm of eternal peace and distance ineffable.

A London Objection to my Testimony when using that Method.

The tube incandescence then is pre-eminently favourable for accurate micrometrical observations. But before I can expect to have my descriptions of what it has revealed to me listened to elsewhere, it will be necessary to meet openly an accusation lately printed against me by that very same British Association Committee whom I have already on other points alluded to most honourably for their ability, and presumed sense of justice. Yet the following is what appears at p. 12 of their Report for 1880, published in London, when speaking of certain of my observations at that date in vacuum tubes :—

"Professor Piazzi Smyth has however not filled his own tubes, and we must be careful not to attach too much value to the labels put on vacuum tubes by the glass-blower who has filled them."

Of course this a delicate insinuation that I *have* been trusting to such labels: if it is not also intended to indicate that he who fills his own tubes, as the actual writer of that sentence for behoof of the Committee of fifteen had done for himself, may take a very high place among the philosophers of the land. While any one who falls short of that particular tubular operation by the smallest item, no matter in what company, or under what system of friendly or scientific co-operation with others,—instantly pitches headlong down a social precipice, and may only bring up afterwards among glass-blowers.

Now it is perfectly true that I did not either make or fill my own tubes; and there has never been any secret about it; for I have from the first joyfully proclaimed who did that for me; and did it at last so well, that I could conscientiously recommend them elsewhere.

For as to the persons concerned, I have been very fortunate in interesting in this matter intellectually, several gentlemen of education, ability, and experience in both chemistry, scientific instrumentation, and business, viz., first, M. SALLERON, and then his successor M. DEMICHEL in Paris; next Mr LOUIS P. CASELLA, and then Mr CHARLES F. CASELLA in London; and finally I believe I may add, to name one deficient to none in persevering enthusiasm to conquer every chemical difficulty that arose in his path, though with little leisure and less of laboratory appointments, Mr W. H. SHARP of Messrs KEMP & Co. in this city.

With one or other of these gentlemen I have been in nearly continued correspondence for the last six years, discussing and trying experiments for the quality of the glass, size and shape of the tubes, materials of the electrodes, strength of sparks, arrangement and bore of capillary, as well as the methods of preparing the several gases, purifying them when made, removing occluded gases from the electrodes both before and during the filling, and then finally sealing. Sealing too not a single tube only, but a series at several stated and pre-determined steps of pressure.

But did I even then trust to either the necessary labels of some kind put on these tubes, or to the long descriptive letters also sent to me?

Certainly not, after the first few days of experience.

For my plan ever since then has invariably been, on receiving a batch of fresh tubes from any maker, to put them one by one into a testing apparatus; find out there what is in them by their stronger lines compared with the general literature of the subject, put my own labels on them, and perhaps send $\frac{3}{4}$ of the batch back to the maker for faults that had escaped him; and then would begin a correspondence to try and find out where, either in the making of the gas, or the steps of its purification, the fault originated, and how it might be avoided in a new set.

Again, even with tubes that have passed this examination, I have usually

reviewed a number of them before any night of final observation for the present paper, in order to find out if any changes with time and use were going on amongst them, and to ascertain more particularly for the service of the great spectroscope, which tube of them all, whatever its original label, was just then capable of showing a particular part of the spectrum of some specially required gas, with the greatest purity and the utmost vigour.

If this is still to be held up to public reprobation by London central and immovable scientific authority, as my "trusting to a label put on by a glass-blower,"—and because I did not fill my own tubes,—there is nothing left for me but to request the Royal Society, Edinburgh, to judge between us,—if I shall venture to set forth, before the close of this paper, how much more of the undoubted phenomena, of at least one particular gas I have succeeded in discovering, identifying, and micrometrically recording on an extended scale, than have any of those London and British Association gentlemen ever been able to observe in their tubes, although they filled them for themselves.

Resuming then, by this Society's leave, we come next to

PART II.

Citron, and Green, Bands of CH, in Vacuum Tubes.

After preliminary experiments with Alcohol, Marsh gas, Turpentine, Coal gas and Olefiant gas—I settled down to working chiefly the two last of these Carbo-hydrogen vapours or gases.

Of these gases much desired, pure CH spectrum, by electric light, but under atmospheric pressure,—MM. Angstrom and Thalen have given the two brightest bands, viz., the Citron and the Green, in their *Mesures Micrometriques*.

Those well-known bands make therein a very brilliant picture, especially as they are engraved in *ne plus ultra* style of both refinement and force; in the positive manner too, or with the lights white, on a field of black for darkness, and with an effect that Rembrandt might have envied.

The Swedish scientists do also there give a considerable indication of hazy, fluted linelets, continually getting closer, and brighter as they approach the least refrangible side of each band. But, strange to say, they have wholly omitted the vastly superior brilliancy of the leading *lines* in each band!

These strong *leading* lines are the first exact features which a beginner in spectroscopy makes out, to his great delight, when studying each CH Blow-pipe band; though at first sight, and with a too broad slit, said bands had probably appeared to him as only composed of smooth haze. And I can now further vouch, that those CH bands' leading lines, whether in blow-pipe or vacuum tube, remain equally conspicuous over the linelets, in all my subsequent

magnifyings up to a size fully 12 times larger than that of the Swedish Philosophers. These lines moreover in the vacuum tubes, are very distinctly double, and get wider and wider in their duplicities, though they decrease their whole distances of double from double, with every succeeding line.

There must therefore, in their omission, be an error in the work of those otherwise unexceptionable authorities; and it is pretty certainly owing in large part to the bad definition, or broad slit of the spectroscope there employed, as well as the greater practical difficulties in the positive mode of representing *bright-line* spectra. For the Upsala linelets are ultra hazy things, running one into the other and making only a confused and slightly undulating surface of luminous fog; culminating too soon, on the red-ward side, into the perfect light, or whiteness, of white paper. Whereas in my Vacuum tubes, far beyond the Blow-pipe's hazy separations already alluded to, the linelets, however faint, are thin and linear; and in some new tubes are capable of exquisite sharpness of definition, on an almost absolutely black field of view.

That however is not all that has to be noted with a very high Dispersion power; for after further working these tubes, the linelets became double, and after that even treble! Such a change however being always the beginning of a tube failing, or going altogether wrong: and was first testified to, as will be seen in Plate No. LIII., by the very superior optical power of a fine Grating which I had the honour of receiving from Professor ROWLAND, of Johns Hopkins University, Baltimore, U.S.; but corroborated afterwards only too abundantly by the older prismatic apparatus. Hence some advantage will be found, when comparing my different views of any of these CH bands, to note the name of the tube employed on the occasion, and the date of observation; a single day, of hard work, often showing great progress in the work of deterioration.

ORANGE BAND OF CH; AND EFFECTS OF PRESSURE, IN VACUUM TUBES SO-CALLED.

For testing my own views of any other than the Citron and Green bands just disposed of,—we must fall back on the general map of the Upsala scientists, small though it be. But it is beautifully engraved; in the negative manner fortunately as to representing light by black; and professes to give the Orange, Citron, Green, Blue and Violet bands. Shading them, however, into striking relief by adding to others closely ruled *vertical* lines, which are a mere engraver's easy method of producing shade, and mean nothing, while they mislead much, in spectroscopy.

Comparing it, however, first of all with my own Index Map of CH in vacuum tubes (Plate LXXVII.)—what is the meaning of the immense force of the Orange band, and at the same time the dwindling down to a mere trace of

the Violet band in the Upsala Memoir,—so very differently to what occurs in that grand constant, viz., the Blow-pipe flame's spectrum of coal-gas and air.

In this last material nothing is easier on any occasion, and for any length of time, than to get all 5 bands to show; but the Orange band is always weak; and did therefore altogether escape some of the earlier observers.

In the tubes also, by electric light, the Orange band is far weaker than either the Citron, or the Green; but it has another difficulty to contend against there, of this nature,—

When the pressure of the CH gas is small, it is so very easily decomposed by the electric spark, that Hydrogen low-temperature lines are set free; and being nowhere stronger and more multitudinous than over the Orange region, they completely mask any residual traces that may remain of Orange CH, and much of the Citron CH, band, as well. But, as I have been finding with tubes specially prepared to that end, the decomposition becomes less and less with increasing density of the filling, until at several whole inches, instead of hundredths of an inch as with the old tubes,—Hydrogen lines nearly disappear, and CH bands like the blow-pipe's bands, so far as their range extends, are almost the only existences visible.

To get the CH Orange band, however, quite clear of those obstructions, is particularly difficult. Thus with coal-gas at 5 inches pressure, last year, every blow-pipe band was well seen, except the unfortunate Orange one; and so it was also this year with a fine tube of Olefiant gas prepared by Mr CASELLA at 2 inches pressure. But with another tube he had prepared at the same making, at 4 inches pressure,—such is the superiority of Olefiant, to Coal, gas for this purpose,—the long desired cynosure was reached at last. For in that tube's spectrum, while not a single low-temperature H line appeared, there was the Orange CH band as perfect in its symmetry of lines and linelets as anything could well be imagined, and as I have never seen it written yet.

There were to be counted in it 5 leading lines very bright and distinct and perhaps a sixth, all at successively smaller intervals in proceeding towards the violet: while between every pair of them, and in the interval beyond of greater refrangibility, were the linelets, in infinite thinness, sharpness, and definition; at first, or towards the red side, very close set, but continually increasing their distances apart, and preserving their inimitable Liliputian visibility, right up to the very beginning of the Citron band. This being a glorious extension of the vanishing side of the Orange band, far beyond anything ever seen with the blow-pipe, or even with tubes, when coal-gas is the filling medium.

Next, turning to the Citron band of CH (in the same 4 inch pressure Olefiant gas tube) its leading lines were vividly bright; its linelets also unprecedentedly clear, and never ceasing for a moment until, although continually

widening their distances from each other, and paling and thinning their light, but not losing their definition, they at last came right up to the Green band.

The Green band as a matter of course began with its "Green-giant" line in magnificent cue; then came closely packed, but well separated, sharply defined linelets; then the second leading line, and wider linelets, then the third leading line and after that the long expanding series of sharp linelets, which continued on, and on, and on, until the beginning of the distant Blue band was reached.

But shortly before that point was arrived at, a broad, faint, grey haze-cloud was passed. I had never seen anything like it, in that spectrum place before. What could it possibly be?

It turned out to be Glaucous Hydrogen. Not in the shape of the sharp and vividly bright line that it always shows in tubes at smaller pressures, but a mere amorphous bundle of Nebular haze.

Turning back then to the Red end of the spectrum, there, in the place of the usual Red Hydrogen line, was another broad cloud of faint haze, but of course red in colour.

This therefore was the reason why even the Orange band of CH, with its ultra thin and sharp linelets, was, for once, not sensibly interfered with by low-temperature H lines. For at that grand pressure of four mercurial inches on the Olefiant gas,—mere nascent Hydrogen could only exist, even with its strongest lines, as a sort of faint vapour, floating like a ghost over certain spectrum places; and all low temperature H lines being vastly fainter than its two just mentioned high temperature lines (Red, and Glaucous)—their resolution into similarly broad clouds, depressed their intensity of light to beneath the *minimum visibile* of any eye.

I spent perhaps half an hour noting these circumstances in the testing spectroscope which has 12° Dispersion A to H, and was planning how I would arrange the great spectroscope of 60° Dispersion, to take advantage of such an unprecedented view of the Orange band of CH,—when I fancied I saw a double line where lately there were only linelets; then a stronger line appeared between two of that band's leading lines: then another, and another. To my horror they began to look amazingly like low-temperature Hydrogen lines. Turning therefore to the places of the late nebulous clouds of Red H and Glaucous H, I actually saw them slowly gathering themselves together, and settling down as lines into their ancient places. While in half an hour more, Red H and Glaucous H were narrow and vivid exceedingly; while the whole band of lines and linelets of this poor, persecuted Orange CH was now hidden in a positive jungle of intrusive low-temperature H lines, of a most provoking degree of strength, brilliancy and number.

My hope then of presenting the Society with a large map of Orange CH, out of that tube, was gone for ever. Because, when decomposition, by spark

illumination, once begins in a CH tube, it never stops until all the H has freed itself from the trammels of connection with C (Carbon); and that element either falls inert, or if it can find any O, combines with that, and appears as CO, to the still further confusion of all CH bands.

At the same making where these two Olefiant gas tubes at 2″·0 and 4″·0 pressure were prepared, Mr CASELLA made for me another tube at only 0″·1 pressure. There was no O nor CO visible there, nor *any CH either*; nothing but the most brilliant set of lines of pure and simple H that were ever beheld, I should suppose, by mortal eye. In fact, at that low pressure, the first spark had decomposed the whole of that faint charge of Olefiant gas; its C was nowhere visible, but its H atoms were vibrating everywhere: and the only consolation I had for seeing nothing of the expected CH was, the apposite illustration that the whole case offered of a favourite idea of the late excellent Sir WILLIAM SIEMENS, whose loss we all deplore. His idea being, that the gases which, by combining under 800 inches pressure on the surface of the Sun, give out light and heat,—may, when excessively rarefied by removal into outer space, become decomposed or separated from each other under even the weakest physical influences; but are made ready in that way, on their return to the Sun, to give out light and heat by renewed combination under pressure, over again.

BLUE AND VIOLET CH BANDS.

Of the Blue band of CH, I have little to say beyond what my readers will find out for themselves, on referring to Plate LIV., to my Index Map (Plate LXXVII.), and also to MM. ANGSTROM and THALEN'S Index Map, which *mutatis mutandis* is fairly enough compatible therewith.

But in the case of the Violet band, so large and bulky with me, so thin, small, and vanishing with them, there is a huge difference to be explained.

Now I should have already indicated that an exactly opposite difference in the case of the Orange band, seemed to be attributable there to the Swedish observations being made on gases at far greater pressure (probably the full atmospheric) than the densest fillings of any of my tubes; and the same reason, though with opposite effects, is apparently the acting cause at the opposite, or violet, end of the spectrum, of what we may note there. For with my own tubes, the denser the filling, the nearer did the Orange band come to the larger Swedish development of it,—yet the nearer also did the Violet band come to the Swedish depreciation of *it*. In fact in my densest tubes I have not only found the Violet band (the furthest visible one of the Coal-gas Blow-pipe series) an almost vanishing quantity,—but have proved an entire absence of a still more beautiful and powerful band beyond it—and which

ought otherwise (as well as another band between the blue and the violet) to be always seen at electric temperature, viz.,

The Marsh–Violet CH Band.

This band was so-called, from Professor Alexander Herschel first finding it during some of these experiments in one of my tubes of Marsh gas; but it was already known to older spectroscopists who have used pure Oxygen, in place of atmospheric air, in their blow-pipes.

With stronger sparks too than my earlier ones, I have latterly found the band developed to more or less extent in every kind of CH gas;—and capable of coming out with far more force and picturesque luminosity that the previous Violet, or the ante-previous Indigo, band.

In short with its very pronounced leading lines, and then the expanding linelets after each of them, in such regular series,—this last and latest "Marsh Violet" CH band may be considered a most typical example of a CH band. It would also probably make a still more magnificent appearance in photography;—for, it is so far within the ultra violet of the spectrum range, as not to exhibit its full glories to the human eye, but is by just so much within the sphere of the impressibility of bromo-iodide of silver, focussed on by quartz lenses and prisms. My own plate of it therefore (No. LIV.) must be looked on as its *interim* presentation only.

Of the Chemical Interpretation of this CH Spectrum.

Through all the variations I have been describing of this CH spectrum, however much more or less may have been visible at its one end, or the other, by reason of accompanying circumstances just explained,—no one known and recognised band in it, when tested by its sharp leading lines has been moved out of its spectrum place by the smallest, recognisable quantity. Hence it is one and the same spectrum throughout all the above intensity variations, and one so continually met with in this world, and in astronomy is so characteristic of the self-luminosity of comets, that it is most important to know what chemical science says as to its origination and nature.

I have been, thus far in the present paper, calling it the CH, or Carbo-Hydrogen, spectrum; but in London among the magnates of Chemistry and Spectroscopy, it has been declared to be the spectrum of C, or pure Carbon alone.

So, too, it was evidently very firmly held to be by them, a few years ago. For when I sent a paper on Auroral Spectroscopy to the Royal Astronomical Society in 1871 making use of the Candle-spectrum as a reference, and attributing it to CH in general, and Acetylene, or C_2H_2, in particular,—I have been

told, informally of course, where a secret meeting is concerned,—that a Royal Society Fellow on the Council of the R. A. S. informed that body that my chemistry was entirely wrong, and my paper was consequently rejected.

Now Carbon has long been known to be one of the most refractory substances under the Sun; though when exposed to the most terrible temperatures of Condensed Induction Electric sparks, it is forced at last, in the unanimous consent of all men, into incandescent vapour, and then gives out a totally different spectrum, to anything we have been describing, viz., one of a few isolated lines merely, see No. 3, Part I. of my Index Map (Plate LXXVII.). This therefore was termed by the London men, "Carbon spectrum No. 1;" while the spectrum we have been discussing, and which may be seen in the base of the weak flame of any little candle whose temperature is low indeed by comparison, was, with them, Carbon spectrum No. 2, or 3, or 4; on the then new presumption that a Chemical Element, instead of being confined to one spectrum alone, may have several.

The history of the origin, and metropolitan establishment, of this very contradictory conclusion for Carbon, is, that Dr ATTFIELD of London in 1862, presented a paper to the Royal Society there, which that body accepted and printed;—wherein he claimed to have seen the banded spectrum of the Blow-pipe flame of Coal-gas and air in every possible compound of Carbon with either H or any other gas; whence he decided, that the spectrum must be that of pure Carbon alone; however different it might be from the English Carbon spectrum No. 1. This decision therefore having been given forth under the auspices of the Royal Society, London, has remained the rule ever since in that region, however violently it conflicts with the Natural Philosophy of the case, and the Chemistry of Carbon in general.

Outside the London circle some very different ideas prevailed; but were ignored by the grand central authority there, until at last the progress of knowledge raised an earthquake in their midst, with effects which would have been far less disastrous, had the London magnates been previously only a little less exclusive. For thus, with a charming *naiveté* of confession, explains the British Association's Report of 1880,—

"On the whole it may be said that, from the publication of ATTFIELD's paper (1862) until the year 1875, every spectroscopist, whether he was a chemist or physicist, who had set to work to decide the question, came to the conclusion that the Candle-spectrum was a true spectrum of Carbon (*i.e.*, of C., not CH), and the question appeared to be settled."

Now I was not original in having, on the other hand, during that interval, upheld the Candle-spectrum to be one of CH, not of C; for I had learned it previously from my friend Professor SWAN, who, with his paper on the subject to this Society in 1856, is an older authority by many years on the Candle-

spectrum than any of the London gentlemen,—and yet, with myself, was pushed out of the pale of recognition through all that long period from 1862 to 1875 But what occurred in that latter year?

In 1875 was published the grand Memoir of MM. ANGSTROM and THALEN, wherein a very polite denial is given to the correctness of one of the most important of Dr ATTFIELD's assertions, viz., that the candle-spectrum was an invariable accompaniment of a CO flame burning in the open air.*

Imperfect methods of preparing CO (Carbonic Oxide), argued M. THALEN, may easily allow CH gas to be present and give its spectrum;—but pure CO does not give it. So also I have found with my tube experiments,—for while some of M. DÉMICHEL's very carefully prepared tubes of CO did not reveal a particle of any of the bands of the CH Blow-pipe flame,—certain other examples of CO by a London maker exhibited so much of the said bands, not too as a mere residual accidental impurity in the tubes, but as a something introduced *pari passu* by an erroneous chemistry in making the gas, *for it increased always with the pressure*, that I wrote at last for the particulars of the manufacture; and then discovered that the maker had been using a very weak and watery example of mere commercial Sulphuric Acid, instead of the most pure and anhydrous example that could be obtained.

The outcome therefore in 1875 of the opinions of such men as ANGSTROM and THALEN, could not be altogether repressed and repudiated even by the Royal Society, London. But that Society has since then had a severer trial to bear; for almost in the *et tu Brute* manner of the stricken Cæsar, they have had to read the later essays of Professors LIVEING and DEWAR, from the Cavendish Laboratory at Cambridge; and find therefrom, that those distinguished scientists have come to precisely MM. ANGSTROM and THALEN'S conclusion; viz., that the Candle-spectrum is a CH, not a C, spectrum; and that its uniformity through all varieties of CH chemicals, depends upon the formation of Acetylene, C_2H_2, in the course of the combustion or incandescence.

In short, the mental confusion that has now overtaken those who have ruled the London world of spectroscopy in this matter, so long,—is illustrated at the end of the British Association's Report upon it;—for it terminates with a disjointed, unnecessary and primitively simple statement of the spectrum places of the mere general beginning of the Orange, the Citron, and the Green bands of what may now be firmly called by every one, the CH spectrum.

Unnecessary was that proceeding of the Committee, because all men have

* From p. 14 of Messrs ANGSTROM and THALEN'S Memoir. "Quant à l'observation de M. ATTFIELD que l'oxyde de carbone donne le spectre ordinaire des carbures d'hydrogène, nous devons remarquer que cela ne s'accorde pas bien avec nos propres expériences.

"Dans un tube de Geissler, contenant de l'oxyde de carbone ou de l'acide carbonique, on peut certainement trouver des traces des spectres des carbures d'hydrogène, puisque le gas n'est jamais parfaitement sec."

been long since agreed on the said places, quite closely enough for identifying the phenomenon; and the Bezonian query of "C or CH" has never yet been attempted to be answered by referring to any doubt about exact Spectrum place.

PART III.

The CO Spectrum.

This CO spectrum should symmetrically arise in a combination of Oxygen with Carbon; just as CH represents Hydrogen joined to the same element; and accordingly vacuum tubes with a trace of Carbonic Oxide (CO) give the spectrum we have now to discuss, in a most marked manner and easily recognisable character.

In my former paper to this Society, I regret to say that I did, though with expressions of considerable reserve, allow for the time, with the English spectroscopists, that this spectrum might be one of pure Carbon, at a temperature between lamp-flame and that of the Condensed Induction spark. But I beg now to apologise for that error, to withdraw the name of "Tube Carbon spectrum,"—and to follow the teaching of Messrs Angstrom and Thalen, who consider it to be the spectrum of the compound gas CO, (Carbonic Oxide) and of that alone; for even if CO_2 (Carbonic Acid) be also in the tube, or even occupy it entirely, one charge of its Oxygen remains ineffective, and exactly the same visible spectrum, as that of CO alone, appears.

Now this CO spectrum, from the materials of its origination, is one of almost as extensive presence on the earth as CH; and has at first sight something of its appearance. Yet they are two opposing and antagonising principles at every step.

Statical Differences.

In small spectroscopes the CO spectrum is so far like the CH, in that it is a spectrum of bands; but it has many more; so that while MM. Angstrom and Thalen have shown in their *Mesures Micrometriques* two only for CH, they show three for CO; and in their general Index Map they have represented 8 principal, 5 secondary, and some 16 very faint indications of tertiary bands, for CO; but 5 only for CH.

The 8 principal bands of CO reinforced by 2 bright ones of the secondary, are, from their spectrum places, of the following notable grades of colour—

(1) Red,
(2) Scarlet,
(3) Orange,
(4) Yellow,
(5) Citron,
(6) Green,
(7) Blue,
(8) Indigo,
(9) Violet, and
(10) Ultra violet.

All these have their brightest, hardest edges toward the red end of the spectrum, in so far agreeably with all the CH bands; while the Citron and Green of the CO bands, fall so nearly on the spectrum places of the similarly coloured Citron and Green CH bands, that beginners may sometimes confound them; or even imagine a physical connection and community between them.

A very little increase however of Dispersive power with Definition, will show that the CO bands have no leading lines in them, like those which are so prominent in CH bands. The CO bands in fact are made up of nothing but very uniform linelets, and therefore present a smoother, more enamelled looking, surface; and they are narrower than those of the other compound.

A far more certain difference however comes out on very highly increasing the spectroscope's powers; for then it will be found that every band of CO has its every linelet of a different construction, or we might almost say material, to any linelet of CH; and every arrangement of them is different also. This will appear perhaps most strikingly on comparing the Green band of either; but as we have already given that band of CH, we have only here to picture, describe and discuss the

Green Band of CO.

In the Upsala micrometrical view this band is very short, and the linelets of which it is dimly indicated to be composed are coarser and wider apart than those of CH.

The shortness of the band, as given, merely arises from the circumstance, that at the point where it is cut off towards the violet side,—Green CH (when that is simultaneously present, owing to faulty chemical preparation of CO, or otherwise) comes in, and one band, after that, overlying the other produces confusion. The Upsala philosophers therefore did well, in picturing for green CO by itself, only that little bit of its Green band by whose small breadth it comes out from behind the bright beginning of Green CH; forming in that way a tiny peninsula of perfectly pure Green CO illumination, which is already somewhat celebrated in spectroscopic story.

A few years ago this peninsula was thought so very narrow, or minute, a quantity, that it was proposed as a test, much better than the Micrometer measures of that day, to settle whether the carbonaceous spectra of Comets belonged to CH or CO.

In MM. Angstrom and Thalen's Index Map, the said little bit measures 0·23 of an inch broad, and the shading expended upon it does not claim to be anything more than engraver's ornament.

In the larger plate of their *Mesures Micrometriques* the CO peninsula of Green measures 1·4 inches across, and shows 14 indistinct or rounded corrugations, or "flutings" of surface.

In my own finally reduced plates it measures 4·3 inches across, and shows no less than 44 distinct and positive lines.

But in the original records of my spectroscope, and which alone I would desire to refer to now (see Plate LXXVIII.), the breadth of the peninsula is upwards of 26·4 inches; and though it shows only the same 44 lines just alluded to,—yet it gives them with a force, a character and an effect that can be attained on no smaller scale; and was the practical mean by which many of them were first discovered to exist.

Though speaking of these 44 luminous existences as lines, yet it is to be remembered that they are nothing but the linelets composing what appears in smaller instruments a smooth shaded band; and with my largest spectroscope, it was the most extraordinary thing to contemplate the broad fields of absolute blackness that separated each one of these vivid, hard, sharp-edged, well-defined lines from its nearest neighbour on either side.

Nor was it less instructive to use a tube containing both CH and CO; and then compare in the same field of view these two opposing principles, as it were, of the Physical world. The unoxidised against the oxidised; the fuel still to burn, against the refuse of fuel long since burnt; this latter the condition of the whole surface of our planet, rocks and water alike, excepting only its coal beds and a little amount of gold and other unoxidisable metals.

The green CH band comes in (as will be very clearly seen in Plate LVIII.) just on the right of the green peninsula of pure CO; and with its doubled Green-Giant line of CH, shines gloriously enough, but yet with a suspicion of haziness along its edges; while its closely packed following CH linelets, though sometimes exquisitely defined, have something of a gossamer weakness and transparency of look. They are like mere filaments of silk, or spider lines at the best; and if doubles are seen amongst them occasionally, it arises probably from a process of decomposition having set in, or Hydrogen freeing itself from all earthly contamination; a liliputian curiosity in a vacuum tube, but the chief acting agent in the mighty red prominences of our Sun, and in the terrific conflagrations of so called new, or temporary, stars.

With CO on the other hand, and its CO linelets, which are the best defined and hardest of diamond-like lines in structure,—if you see them once, you see them always; fixed like the rocks; or even growing in their places; for when once Oxygen has got hold of any Carbon, all the further actions of the illuminating spark seem only to enable it to go on taking an equally firm hold of all the rest of the carbon that may be within its reach.

In fact, while the usual mode of failing for any CH tube by powerful sparking is to end in its showing nothing but H lines, so for tubes containing any compound of Oxygen, it is to finish by showing nothing but the CO spectrum. And if it has been said, that in the event of a solar conflagration

of this world, nothing of its solid material would be left, except atoms and molecules vibrating in the intense light and heat, we may be pretty sure that while Hydrogen would be dancing like the fire-fiend above the scene of destruction, the more stolid CO would dominate beneath.

Its Numerical Explanation.

But would such a reproduction of Nebular haze bring back the chaos, the confusion, of the Greeks; or would it be an entrance into a superior realm of law and order, in number, weight, and measure?

Let the 44 lines in this Green peninsula of CO, now first rescued from the very bad definition, uniform haze, and contracted views of the old observers,—answer for themselves.

There are evidently amongst them, on the grand 26· inch scale, lines thick, and lines thin; lines single, and double, and triple; some expanding their distances apart in the direction of the violet, and others towards the red; there are places of unseemly crowding together of many lines, and other spaces which are comparatively bare,—in short, a careless viewer would pronounce at once for confusion. But having fortunately sent one of the original, and raw, but large sized instrumental records to my friend Professor Alexander S. Herschel,—he was enabled by his experienced study of such phenomena to return in three days a demonstration, that each of those 44 lines was a necessary step in a remarkable system of physical numeration, proceeding in two rows of simple arithmetical progression, one over, but slightly advanced upon, the other; not accidently or discordantly,—but so as to set forth the unit, the quinary, the decimal, and even the quinquagesimal standard of what may be now termed the CO system of linear construction.

The success of this numerical demonstration, this extraction of scientifically ordered simplicity out of at first sight extreme complexity, may be quickly judged of by reference to the large Plate No. LXXVIII. prepared especially to show it; but more completely still, by reading Prof. A. S. Herschel's letters in Appendices Nos. I. and II. Their account is happily so complete, and so independent, as to leave nothing further for me to remark upon here, except observationally; for theory in this case has given pretty certain indications that 8 lines out of the 44 which I have set down as single, are really doubles; but far closer than anything which I have yet been able to resolve. These cases must therefore be left to future observers, a test for their instruments to come; and a still further proof we may expect, when it does come, of the exact geometrical foundations of the very smallest components of the ultimate materials of Nature.

Remaining Bands of CO.

Of the Red, the Scarlet, the Orange, the Yellow, and the Citron bands of CO below that Green band which we have just been discussing; and of the Blue, the Indigo, and the Violet bands above the Green,—and which are all pictured in the Plates Nos. LVIII. and LIX.,—their linelets seem to have somewhat similar characteristics on the whole to those of the Green band,—but with compound variations,—not yet fully made out by observation. Nor perhaps very soon likely to be much further elucidated, because

(1) The dispersion of my present Prisms below the Green is too small;

(2) Above the Green the definition is not sufficiently good;

(3) Towards either end of the Spectrum the illumination of my existing sparking apparatus is not sufficiently bright; and

(4) It is very difficult to get those bands perfectly free from impurities of CH, H, and other gases.

I will therefore at present proceed to a provisional termination of the CO subject, by means of a few words on some general characteristics of that compound gas in vacuum tubes.

A small pressure of the gas, say 0·25 inch, seems to be most suitable for securing a maximum of brilliancy conjoined to stability. For higher pressures, say 1 inch, 2·5, 5·0, or 12·5 inches, simply show the same spectrum, but fainter and fainter as the pressure is greater; while lower pressures, say 0·1 inch or under that, though exceedingly brilliant for a time, are very apt to get their tubes overheated and loosened at their electrodes with loss of illuminating power altogether. To prevent this catastrophe, the electrode ends of the tubes, whether with platinum wires as usual passing through them, or coated only with a film of silver outside, have been made to dip into vulcanite insulated basins of water, and receive their electric charge from thence; but the illumination was never at its best in that manner, the whole apparatus sometimes became inconveniently charged; and with the silver coated tubes, the glass was actually perforated sooner or later. Some of the best exhibitions, however, of the CO spectrum, have been the unintended ones; as of tubes prepared with Oxygen alone; and showing at first the Oxygen spectrum, but that changing during use into CO; and always more and more quickly or inevitably, the weaker the pressure at which the Oxygen had been sealed in.

Whence comes the C for this transformation of O into CO?

Some persons have suggested, from the use of a coal-gas, in place of a hydrogen, blow-pipe in working the glass; and an extraordinary hypothesis has been recently started in Germany, of Si being convertible into C in vacuum tubes.*

* The following note has been furnished to me:—"Herr Wessendonk prepared Siliceous gas with most scrupulous care and purity, without being able to obtain a trace of Silica lines, only CO bands over and over again, and more and more brilliant the purer the gas he used. *Silica* could never be found,

But my own idea is still, that it may be owing to the electric spark's power of convecting C along its wires; and then, not merely because such wires are usually coated along their whole length with an easily melted material so rich in C as Gutta Percha,—but because the Induction coil itself is, throughout its chief bulk, little but a huge mass of soft C; and the rolled up insulated wires inside it, make it a perfect ganglion for accumulating all possible transportable atoms of that element.

Some small spectroscopic evidence in this direction too, is already in print; as thus, plate i. of M. Lecocq de Boisbaudran's admirable book *Spectres Lumineux* gives two pictures of the electric spark in open air; one near the positive, and the other near the negative, Pole. They both of them exhibit chiefly the well-known low-temperature Nitrogen bands; but the latter, or Negative Pole's end, has a glorious distinction from the Positive's, in this, that it has also a very strong violet line, the α, or chief of the whole display, which does not belong to the simple Nitrogen's or to the Air's low-temperature spectrum at all; nor to their high-temperature spectrum either.

To what then does it belong?

According to my earlier and perfectly independent "gaseous spectra" paper to this Society in 1880, it is the characteristic line of Cyanogen, or Carbon combined with Nitrogen, the chief constituent of our atmospheric air. Carbon vapour then added to the spark which is producing the Nitrogen spectrum in the open air, can hardly but produce this Cyanogen leading line; and such Carbon can be obtained by the electric current from nothing so readily as the gutta-percha, vulcanite, and waxed, or resined-paper interstitions, which form so notable a portion of every Induction coil.

But as I had an opportunity of setting forth something of this view in *Nature* journal last year, assisted by a woodcut of the spectra,—I here close this part of the present paper on the two compound and opposed gases, CH and CO; in order to proceed to the next part treating of the three elemental gases H, O, and N.

PART IV.

THE THREE ELEMENTAL GASES, H, O, AND N.

Subject 1.—H or Hydrogen.

There is little trouble in procuring good H tubes; and they are such excellent illuminators as to get the better of all ordinary impurities, espe-

in any quantity to speak of; so it could not have come out of the glass. SiH_2 and $SiFl_2$ were used (very easily prepared pure). CO was the only result he could possibly obtain. That, and always that."

cially with time and use; and show at last nothing but the Hydrogen tube-spectrum with brilliancy and certainty at any pressures between 0·1 and 0·5 inch.

One particular impurity, however, has to be guarded against; for its lines though few, are strong, viz., Mercury,—whose vapour always has a chance of entering, in connection with the Sprengel air-pumps now so generally used in the exhausting operations. To this end therefore some tubes specially containing Mercury have been made for me in Edinburgh by Mr W. H. SHARP (of KEMP & Co.), and have furnished the Mercury low-temperature spectrum which appears as No. 13 in the second division of my Index Map; and will enable any one with great ease to eliminate Mercury, from the H, lines; especially if they try it at various lamp temperatures.

But not a great deal has yet been written on the tube, or "low electric temperature," H spectrum, though every one knows about the 4 grand lines in its high-temperature spectrum, and which reappear in the tubes, together with all their low-temperature lines. MM. ANGSTROM and THALEN, for instance, are silent on the subject in 1875; and still more remarkably Hydrogen does not figure in the otherwise very comprehensive list of gaseous spectra treated of by the British Association's Committee's Report of 1880.

Fortunately these low-temperature Hydrogen lines attracted the attention several years ago of the *savants* of the Imperial Central Observatory of Russia at Pulkowa; and Dr HASSELBERG, their chief spectroscopist (a former pupil too of M. ANGSTROM), entered into the subject with intense enthusiasm. He had begun with other gases, but soon alighted, as I had done in my paper of 1880, on the existence of low-temperature lines, as an addition to the well-known high temperature spectrum of 4 lines only for Hydrogen. He found them too so invariably in any and every mode of preparing Hydrogen gas, that he concluded they must belong to it alone, and under such impression prepared a map of them about 18 inches long, with three of the four great lines introduced amongst them.

But that size of map he afterwards considered did by no means do justice to the richness of this H spectrum, wherefore he laboured again with new prisms; and in the course of last year, published with the Imperial Academy of St Petersburg, a new map of Hydrogen "tube" lines by simple electric spark, or the many low-temperature + the few high-temperature lines; the map having a length altogether of nearly 90 inches from the Red to near the Violet line.

This last map of Dr HASSELBERG's is a very grand work as compared to anything yet published, either on the H, or indeed any other, gaseous spectrum; and it will doubtless be long regarded as a high authority for the absolute spectrum place of the lines which it contains.

Hardly so, however, for either the number or minute physiognomy of most of its lines; for whereas the Doctor begins the low-temperature H lines far within, or above, the great Red Hydrogen or C line of the Sun,—I have found them commence far without, or below, Red Hydrogen; continually increasing too in brightness as they pass that line, and at length join on to Dr HASSELBERG'S earliest lines, which are with me very bright. And then again, his scale of 90 inches must necessarily fall lamentably short of a 480 inch spectrum, when it is a question of detecting a close, double, or triple, hitherto recorded as single only.

This indeed by itself might have been got over, or apologised for; but unhappily the laborious author has allowed his engraver to exert his own taste in doubling and frebling the chief part of his principal lines, and even making a banded group out of the grandly single line Red H, in a manner, and to a degree which must entirely mislead the spectroscopic searcher after micrometrical truth.

Now my own original measures of this spectrum, though they cannot pretend to compete with his for accuracy of absolute-spectrum place, are on such a scale that from the earliest Red to the Hydrogen, Violet occupies as I have already mentioned, a continued length of 120 feet. So that if, in this grand hall, you imagine the spectrum strip to begin over the President's Chair, and extend thence continually towards the right, the red and scarlet would reach the end of that wall, the orange would cross that end of the room, the yellow, the citron, the green and the glaucous would occupy all the other long side of the room, the blue would cross its further end, and the indigo, the violet, and the ultra violet would come back and overlap very nearly the beginning of the spectrum's scroll right over the President's head.

Along with that immense length, truly immense considering it is merely a magnification of a slit about $\frac{1}{300}$ of an inch wide,—you would see nothing of bands of CO with their orderly, closely set regiments of linelets, nothing of the leading lines and fainter linelets of CH,—but only lines and lines and lines again, free, easy and distinct of H. There are some 1625 of them absolutely recorded at the instrument; generally they are brilliant, well-defined, showy lines; nowhere very closely packed, but forming all the way along an independent kind of open groups, which have perhaps a certain kind of family resemblance among themselves, but with never any precise repetition between one group and another, either of its strongest single lines, or the occasionally exquisite doubles or trebles which try all the powers of the best spectroscopes yet made to resolve them. In short Hydrogen, in between the positions of its four grand high temperature lines, shows in these almost endless low temperature lines of the tubes, nothing but a saltatory sort of movement, such as an ariel sprite might indulge in, and such as does typify the

taste or the instinct of Hydrogen to shake itself loose from all terrestrial matter, and rise above all the other elements the lightest and most ethereal of them all.

But my apparatus is still so far from describing all that Hydrogen has to show, and which future observers may discover,—one does not know how soon,—that I make no attempt in the present state of the question to try to develop the kind of order on which its arrangements are founded;—but would beg leave to call attention, by its means, to a general feature touching definition in all bright-lines pectra, viz., excepting some of the fainter lines in the ultra Red, the definition of Hydrogen lines is inimitably fine and sharp through the red, scarlet, orange, yellow, citron, and green until we come near the blue, where a little falling off sensibly occurs. In the further Blue and the Indigo the defalcation increases; and in the Violet becomes unbearably offensive; so that what should be a sharp line of light, becomes more like a dull, broadened, or diffuse woollen cord or hazy band.

Is this change which thus supervenes on approaching the Violet end of the spectrum, a fault of the instrument; or a quality of Nature; or a failure of the human eye?

Not a fault of the particular instrument built up by me in rather rough and economical fashion, because I have met the same principle of effect in every spectroscope I have looked through,—even including that charming instrument, the Cooke-Monckhoven spectroscope of Professor TAIT's Natural Philosophy Laboratory,—a spectroscope whose every adjustment is carried out to perfection, and where nothing seems to have been omitted or neglected.

Nor is it a necessary, and innate quality of Nature; for exquisitely defined spectrum lines in both the Violet and ultra Violet regions are said to be obtainable, and have I believe often been obtained, though not by me, in the medium of Photography.

Then the failure must arise in the eye. Yes, in the human eye and its total inability to distinguish between Violet as it is in the spectrum, and every other so-called Violet colour under the Sun. For these, so far as I have yet examined, whether in chemical solids, or fluids, flowers or stained glass, are nothing but a mixture of blue and red; and are allocated to a totally different mean spectrum place than that of violet, by the more than man's discriminating power of either the prism, or a diffraction grating.

In fact, except for the purpose of establishing a sort of border neutral territory, where eye-results may be compared with the blackened imprints on bromo-iodide of silver, so extra sensitive to violet light,—no eye observations should be trusted for minute features and full effects, much beyond Glaucous Hydrogen,—for there Photography can be brought in with advantage, and probably will be, before long for everything, by those eminent scientists who

have of late employed that method in their own special researches, but usually on a far too miniature scale to satisfy present requirements.

Subject 2.—O or Oxgyen.

With this gas comes in a change; a relief perhaps to many persons after the growing complexities of other spectra.

So far at least as the O spectrum has yet been seen and published in vacuum tubes, it is simplicity itself; and though called "the compound-line" Spectrum of Oxygen, that name was given to it merely in deference to a theoretrical idea, in accordance with which the lines *ought* to have been compound; or at all events totally dissimilar to what has been termed, by way of pre-eminence, "the line" spectrum of Oxygen;—because that is what results from the high temperature of the jar, or condensed discharge of induction sparks,—in contradistinction to the low temperature, or direct discharge, of the simple spark, which we are now dealing with.

Of this low temperature, "called" compound-line, Spectrum of Oxygen then it is, that the British Association's Report speaks, when it declares it to consist of four lines only; one in the Red (or Orange rather), two in the Green (or rather one in the Citron and one in the Green), and one in the Blue (or rather between the Indigo and the Violet); but the spectrum places of all four have been accurately measured in Wave-lengths, so that they can be easily identified by any one.

A gaseous emission spectrum then, consisting of four widely apart lines only, must surely be as simple as any one could desire; and the statement is founded on very high authority, viz., a paper by one of the British Association's Committee, printed by the Royal Society, London, in 1879. The author of it too, —being one who not only "fills his own gas-vacuum tubes," but who launched the depreciating accusation against me that I did not perform that operation for myself (pp. 11 and 12),—I shall hardly be allowed, by either of those two great English Associations to put forth any accounts of more lines than their four; and yet, if my mode of arriving at more than four had been dependent on my filling my own tubes,—would there not have been a chance of my being compared to that publie lecturer who, about half a century ago, in London, undertook, in defiance of the doctors, to drink off half an ounce of Prussic Acid, ot deadly strength according to the Pharmacopeia, but stipulated that he must prepare the fluid himself!

Before relating however what I have found, and how; viz., by open methods which should bring out the same result in whatever part of the world they are performed, and have brought out the same in the hands of both French and English workers;—there is something more to be precisionised in the Royal

Society's printed paper alluded to. The letterpress thereof certainly speaks of four lines only, and gives the places only of 4, in figures; but in the map accompanying them they are made into 8; viz., each line of the four is made a double line; two, much more distinctly so than the other two. It is not for me to pronounce on the accomplished fact of the Society's thus doubling the number of lines in a very scantily furnished spectrum; and making the original single lines of observation conform more nearly to the theory they publish, by representing them "compound" to the extent of doubling each one,—but it is absolutely necessary for truth's sake to warn all into whose hands the Philosophical Transactions may come, of the absolute falsity of the (London) Royal Society's Oxygen spectrum plate, in that respect.

The talented author of the paper, moreover, has never claimed to have seen more than four single lines, placed as described; has made an immense number of most admirable experiments to assure himself that they belong to pure Oxygen, and not to any accompanying impurity,—and that there is nothing else in the O spectrum of equal visibility. That degree of visibility however, being something very small; for Oxygen gas is what is generally known, as a bad illuminator, in all vacuum tubes.

There then, with only *four* truly observed lines, the tube spectrum of Oxygen might have remained, had I not in 1879, independently of the late energetic Dr VAN MONCKHOVEN, both struck, and worked out, the idea of using vacuum tubes end-on, in place of transversely to their capillary part, as others seem to have done universally before that time; some of those earlier observers even using the tube's upright line of light, in place of the slit of a spectroscope proper. But with the new end-on vacuum tubes, and equally when they were made for me in Paris, or in London, I immediately, through the greater brightness of their light, saw the presence of many fainter features constant in, or evidently belonging to, the O Spectrum of the four lines.

First, for instance, I found that three, out of the four, primitive lines were, each of them, a triple. Each triple a long way from its nearest neighbour, but of precisely similar build; and I have since then discovered three other such triples, one of them further away towards the Red, than the longer known Orange one; and two others further towards the Blue, than the older Green one.

They make moreover a remarkably connected, though wide apart, and only faintly luminous system altogether, extending through so great a range of the Spectrum as from Red to Glaucous; for the six triples are arranged in three pairs, whereof the mean place of the third pair is from the mean place of the second pair, close on half the distance that the mean place of the second is from the mean place of the first; while at the same time the much smaller distance apart of the sixth triple from the fifth is just about half that of the

fourth triple from the third; and that is again about half that of the second triple from the first. And finally, to carry the principle still further into details, but these details supposed to be more nearly eternal than worlds, and suns, and stars,—in each of the six triples the third line is about half the brightness of the second, and at half the distance from it, that the second line is from the first line.

Indeed the characteristics of an Oxygen triplet are so peculiar, and so closely adhered to in every instance, that I have been able in some tubes swarming with lines of impurities to pick out an Oxygen triplet, as easily as one would distinguish in a crowd of civilians, a soldier with cross-belts and scarlet coat.

Although then there is so little show of general light in a pure Oxygen tube, geometrical order is preserved there amongst such lines as it does show, most rigidly. So that while Hydrogen, with its multitudinous, brilliant, varied lines dancing or vibrating through the whole length of the spectrum, may be likened to a big, curly-haired, Newfoundland dog, bounding about and barking at its own free will,—Oxygen is a Bull dog which, without any show, runs straight to his quarry and holds him fast with an iron grip.

This view, moreover, trifling as it may appear, comes out more notably still, when we attend to the many single lines which there are, after all, in the Oxygen spectrum, and are shown both in my Index Map, and the larger plates, Nos. LXVI., LXVII., LXVIII., and LXIX. For, in spite of its faintness of light, Oxygen in the spectrum actually outflanks every other gas. That is to say, it begins with a very well marked and sharply defined line, further away into the ultra-red than any line, band, or haze of any known elemental gas. This same lowest line too of the O tubes appears to be identical with the most red-ward line in the jar-discharge in the open air, as described in my recent paper to this Society on BREWSTER's Solar line Y.

SUBJECT 3.—N OR NITROGEN.

This is the last gas I have observed on the present occasion, and its spectrum is in many respects the most mysterious, and most multitudinously lined of all, when seen with great dispersive power; for otherwise, it is an affair of hazy bands alone.

Just as it was with O, so here, *mutatis mutandis* is it with N, that a condensed induction spark, or jar-discharge, discloses the high-temperature, or line, spectrum of the gas; and if the two gases be mixed together as they are in the atmosphere, the same discharge shows the line spectra of both gases overlying or multiplying each other; as may be seen in the upper portions of of the Index Map; forming hazy lines when in a dense, sharper lines in a

rarefied, medium; but evidently the same linear spectrum in each case, and of but a few, say a score or two, lines even at brightest.*

With the simple or direct spark on the contrary in the open air, those two spectra vanish, and are replaced by other two, perfectly different; whereof, as just described, that of O is barely visible to moderate power, even in its isolated compound triples or the stronger of its single lines lately discovered; while N is heavily conspicuous all along the spectrum in the shape of a closely packed arrangement of numerous, narrow bands. In a vacuum tube of N alone this arrangement is still more brilliant, is generally known as "the band spectrum of N," and "is one of the most beautiful," says the British Association Report, "which can be observed."

The best map of it I have yet seen is that in ANGSTRÖM and THALEN'S paper of 1875; a map about 27 inches long, and exquisitely engraved; *i.e.*, so far as engraver's work alone is concerned, for the vertical lines wherewith the bands are shaded are engraver's ornament only, and have no pretension to representing lines seen by the observer. But with this reservation accepted, the map effectively reproduces all that was known of the spectrum until 1880; when Prof. ALEX. S. HERSCHEL communicated to this Society some notable extensions of the spectrum into the ultra red, which he had just then made with my Spectroscope as it then was, or merely in a pretty good condition.

His whole conclusion I believe was, that he could identify many more of the narrow bands of N, in that lower region, far beyond or outside the place where the first of THALEN'S pictured bands begin. And he could even trace them up to a place where a triplet of sharp lines shot up, and seemed to form a sort of fountain head, whence had flowed down the continued stream of Nitrogen cross-bands all through the Red, the Orange, the Yellow, and the Green of that spectrum.

With my present improved instrument, and several new and exquisitely pure tubes of N prepared for me by both M. DEMICHEL in Paris, and Mr CASELLA in London, at various pressures between 1·0″ and 2·5″,—I have been enabled somewhat to modify the above view, as thus,—

(1) The band spectrum of Nitrogen, even in those brilliant colour regions just cited, is by no means one uninterrupted series of similar bands,—but is a succession of four large groups of bands; each group bringing in with it slight variations on the preceding one, and separated from its neighbour group on either side, by a tolerably distinct breadth of 2 or 3 bands of weaker action.

(2) THALEN'S first band, though no longer to be regarded as the first band or beginning of the N spectrum, is yet the first band of its own, or the Red, group; which we may therefore worthily denominate THALEN'S group.

* The manner in which the Red Hydrogen line comes into that Spectrum, is very striking, and I have not yet seen a good reason given for it.

(3) Outside and far away into the ultra-red, more N bands do extend, as Prof. HERSCHEL saw; but they form a group of their own, beginning in faintness far beyond Prof. HERSCHEL's triplet of lines, or anything that he saw; rising in intensity of light and markedness of physiognomy as they pass that triple of his, and finally subsiding again very materially before they join, but unsymmetrically, the first band of the THALEN group; for which features please to examine, first the Index Map, and afterwards Plates Nos. LXX. and LXXI.

(4) Prof. HERSCHEL's triplet of lines is however a very interesting existency, with nothing else like it through all the rest of the N spectrum, and with these two following features in addition,—

(*a*) It is shown only, so far as I can make out, in N tubes at very small pressures, say under 0·1″; for brighter tubes as to the bands but at greater pressures, say 0·5″ to 2·5″ show nothing of it.

(*b*) This triplet of lines, so anamolous in the tube, and unsymmetrically placed as to the bands of the ultra-red group which pass in front of it,—is nevertheless owing to the N gas; for it appears to be identical with the triplet of lines which I discovered last summer in the jar discharge in the open air. The one line seen on that occasion outside the triple, has since then been identified with Oxygen; but the triple having no resemblance to anything in that spectrum, can hardly be of any other than N material, and may be deservedly noted as HERSCHEL's N triple.

If the large Plates of the N spectrum, Nos. LXXI., LXXII., and LXXIII., as observed by myself be now examined, it will be seen that THALEN's Red series of bands opens a more brilliant portion of this spectrum; and one which, in and after its third band, effloresces into almost an infinity of the closest and most exquisitely defined lines and linelets that were ever packed into a telescopic field of view. Nor were they all revealed even then, for amongst them seemed to be doubles, or other multiples so exceedingly close that they passed the power of my spectroscope, even at the best, to resolve with certainty; and how many degrees further their intricate refinements of structure extend through the residual haze, of which a little still appears,—it is dangerous to speculate.

Had it not been for the method I elaborated of recording any number of micrometrical places of lines consecutively, and without taking the eye away from the eye-piece,—the attempt to note the exact place of each and every one of such legions of lines in the usual micrometrical manner, would have been hopeless; for at the average rate of closeness of those which I could separate, there are probably 4000 in the first half of the N spectrum alone.

The brightest example of the N tubes, viz., one at 0·1″ pressure, broke down, I regret to say, early in the work, or when I was using it near the D

region; the rest was therefore recorded by means of a 0·5″ pressure tube, compared occasionally with 1·0″ and 2·5″ pressure tubes.

Of the gradual swellings and subsidences of brightness in each of the four long groups of bands (the red, the orange, the yellow, and the green), and the minute variations introduced into the composition and settings of the linelets forming all the several bands of one group, compared with all those of another group,—the Plates Nos. LXXI. to LXXIV. will give a better and quicker idea than verbal description. And they will also indicate well the immense change which comes on in the Glaucous region, making the rest of the Nitrogen spectrum, through the Blue and Violet an utter contrast to its earlier appearance from ultra Red to Green.

This difference is marked strongly in ANGSTROM and THALEN'S map, in so far as those classic authors represent the Blue and Violet bands much broader than the Red and Yellow. But they have wholly missed the club-like, or fascicular, groups of lines with which each such Blue or Violet band commences.

I have had therefore to alter my Index Map considerably from theirs, in order to represent this most innate and valuable distinction, as it appears to me, of blue N, from blue CO, bands when in close neighbourhood. And the minuter construction of these clubs of lines may be made out pretty well in the larger plates of N, as Plates LXXV. and LXXVI., notwithstanding the characteristic bad definition of any and all spectral lines in the Blue and Violet.

There is another peculiarity, however, well worthy of note in these more refrangible and very broad bands; viz., that there is another class of bands with sharper beginnings mixed up with them; and these additional, or smaller featured bands (unnoticed I believe as yet by other spectroscopists), are more constantly and certainly seen in tubes prepared for N, than those prepared for N_2O, or Nitrous Oxide. Or, in other words, the N_2O Spectrum is simpler than that of N; though the chemical notation as it stands now, is more complicated.

But I have no maps of the Nitrous Oxide spectrum to show, on account of all the N_2O tubes, after a preliminary eye survey had been taken, having gone wrong spontaneously, while I was observing those of N; and I had no more funds for further tube making.

My present task therefore is finished, save a few words, or perhaps mere conjectures respecting the possible chemical origin of the spectra just described for

THE THREE ELEMENTAL GASES, H, O, AND N.

PART V.

Concluding Notes on the Elemental Gases, H, O, and N.

If in the earlier part of this paper, we found it expedient to admit that the two separate spectra there described were the spectra in each case of a compound Gas, viz.; the one of CH and the other of CO; and to some degree because the high-temperature or jar discharge gave a totally different spectrum to C alone; is there not something rather similar to be said touching the spectra we have just been describing for H, O, and N, though they are simple and elementary gases according to the Chemists?

There is at least in so far, that if we try said reputed simple gases, not with the weak direct spark which we have been using all along, but with the intensified or jar discharge, there is introduced for each of them a totally different spectrum from that which we have been describing. But why, in that case, are our tube spectra of those gases not ascribed to compounds of each of them with some other, in place of being confined to the one gas alone?

Partly, I imagine, because no one knows at present what the other component may be. And partly because there is a very conveniently classifying theory for use in the meantime, which sets forth how one, simple, elemental gas may have two or more different spectra under different temperature circumstances; granting always that it exists as a gas at those temperatures, and is not, like Carbon, inert and solid at all but one of them.

M. Thalen has controverted the multiple view for gases in general, not only on the grounds that his deceased, revered, and loved friend M. Angstrom held that each chemical element *could* have only one spectrum under any, or all, circumstances (though how proved is not stated)—but considers he has demonstrated that the low temperature or "Band-spectrum" of Nitrogen, is the spectrum of the bi-oxide of that gas, and not of that gas by itself.

In 1872 (*Proc. R. Soc.*, xx. p. 482) Dr Schuster, the able writer of the Report for the British Association Committee in 1880, held a similar view. But in 1880 he repudiates the idea, and states that no *emission*, or bright, spectrum has yet been found that can with certainty be referred to a compound of Nitrogen and Oxygen; so that he restores the "gorgeous Band-spectrum" to Nitrogen alone; its *line* spectrum at higher temperature notwithstanding.

Dr Schuster is also the hero for claiming the particular Oxygen spectrum we have been describing, viz., the spectrum of minute triplets and a few thin lines, for Oxygen alone; calling it the compound-line, or low-temperature, or simple-spark, spectrum of that gas; but without invalidating in any degree its claim to the strong Line-spectrum which it shows at high electric temperature.

And Dr HASSELBERG seems to perform a somewhat similar part for Hydrogen, excepting that there, the high-temperature lines are seen simultaneously, or together, with those of the low-temperature spectrum.

Of these three elemental gases, all of them equally and similarly disputed upon, the case of Oxygen is perhaps the most advanced and instructive.

With simple, direct, uncondensed induction sparks, passing through an Oxygen vacuum tube, every one allows, or will allow I hope after reading this paper, and severely experimenting, that he does, as he should, get that spectrum of minute triplets which I have been describing here at length. And every one also allows, and has allowed it for many years past, that if you send a sufficiently condensed, intensified, jar discharge of induction electricity through the same tube, the spectrum immediately changes to something perfectly different, viz., the high-temperature, or line-spectrum of Oxygen, as set forth on strips Nos. 7 and 8 of our Index Map, Plate LXXVII.

The facts therefore are allowed, and it is only the interpretation of them which is different with different parties. One side insisting on a different vibration of the same particles of Oxygen, under the two kinds of electric sparks, being the only reason of the two totally different spectra; and the other declaring that with the milder spark, the Oxygen *must* have entered into momentary chemical combination with something else that was already in the tube, but unperceived by, and totally unknown to, its owner.

There is little doubt too that there may be many more infinitesimally small things in a tube, or extractible out of its sides by electric discharge, than chemical philosophy is at present aware of. While even with so gross a matter, as CH in sufficient quantity to give strong spectral bands,—we have seen London scientists going on for years preparing CO, and quite unconscious that they were at the same time manufacturing CH with it, even *pari passu*. Some particular kinds of gaseous impurity that may be in a tube, adhering to its sides or otherwise,—I have shown in this paper may be easily submerged by greater density of another gas thrown into it. But if that gas be contaminated at its birth with some other, either not yet recognised by Chemistry, or in too small proportions to be detected by any existing chemical method,—who shall help! There may have to be a new chemistry elaborated, dealing with infinitesimally small combining quantities. But that is something so hazardous to count upon, that we may well in the meantime accept the varying temperature vibration theory, as a mere method of classification; and then we shall find that there is an immense deal yet to be done, in order to collect even the plain and practical facts of the spectra of the best known gases, in such degree of purity as they can be prepared in, at present. For with every *elemental* and *permanent* gas, *i.e.*, gaseous at all known temperatures and moderate pressures,—there seem to be three different temperatures under which its spectrum in some

shape may appear, viz., the temperature of the condensed spark, the simple spark and the atmospheric or auroral.

With *compound* gases, there are only the two latter temperature stages, viz., the simple spark and the cold auroral; for the high-temperature condensed spark resolves them instantly into their known chemical components, which then give out their own elemental spectra. While with *Carbon*, and every other similar solid, there is only one temperature stage; viz., that highest one at which alone it can be volatilized.

To return then to the *elemental* and *permanent* gases, as the completer system, how little do we know yet of all three varieties of spectra belonging to any one of them;—not to say anything of each variety, in order to be fully understood, requiring to be made to appear *first* as an emission spectrum with bright lines in a dark field, and *second*, as an absorption spectrum, with the same set of lines but dark in a bright field.

Suppose we take Oxygen again as an example.

1. Its emission spectrum of bright lines in the condensed spark, or jar discharge has been grandly studied by KIRCHOFF, THALEN, PLUCKER, and HUGGINS in long past years, with a most satisfactory cataloguing of Wave-length places again and again,—and yet it was left for me to discover the earliest of its ultra red lines last summer. But no one has yet seen either that line, or I suppose most of the others, as dark, or absorption, lines; though Professors LIVEING and DEWAR are now working at that subject, and towards that end very magnificently in the Cavendish Laboratory at Cambridge.

2. Oxygen's emission spectrum in the simple spark, viz., the spectrum of minute triplets and a few thin lines, has been set forth in this paper at some length, though elsewhere, and particularly in London, only 4 lines of it have been recognised; but none of them have yet been seen by any one as a dark absorption spectrum, so far as I am aware.*

3. At the atmospheric, the cold, or auroral, temperature no one has ever yet seen any bright, or emission, spectrum of Oxygen. But two persons are said to have recently seen its dark, or absorption lines connected with that very low, or non-fiery, temperature; and it came about in this manner.

After I had for years and years besought, but in vain, the rich London Societies, or the Government to make the enormous experiments which are necessary for the purpose,—these have recently been made in St Petersburg! There, in connection with the University of that city, M. EGOROFF, with his friend M. KHAMANTOFF,—so far as we can trust the rather too scanty information yet given out,—established a horizontal tube 66 feet long with glazed

* I thought, on the first discovery of 3 of these triplets, that they could be recognised in ANGSTROM's Normal Solar Map as dark Fraunhofer lines, but I delay now either affirming or refuting that idea, until I have made more satisfactory and exact observations on the Solar Spectrum itself.

ends; filled the tube with pure Oxygen gas at several atmospheres pressure, looked into it at the near end with a powerful spectroscope, while an incandescent lime-light was placed outside the other end;—and then, pictured on the bright continuous spectrum of that light,—they inform us they saw and measured certain most distinctive bands and groups of dark absorption lines. These were totally different in both arrangement and spectrum place from any of the bright lines of either the high-temperature, or low-temperature, sparkings already described for Oxygen,—but they were held, nevertheless, to be Oxygen lines, because they were only seen when that one particular gas, in immense excess, was introduced into the tube; while there was quite lowering enough of temperature between the simple induction-spark and atmospheric temperatures, to permit of another kind of gaseous vibration being set up, if that was already allowed to be possible, between the simple, and the compound, spark, by reason of the latter's superiority therein.

The special interest, however, of the St Petersburg experiment, if confirmed, depends still further, and more pointedly, on this other observational fact; viz., that the dark absorption groups which MM. EGOROFF and KHAMANTOFF saw in their Oxygen tube they declare to be identical in build, and spectrum place, with the powerful groups of similar dark absorption lines, telluric chiefly, but perhaps partly Solar, or extra-Solar,—seen by all the world constantly in the spectrum of the Sun's light, and so well known there as FRAUNHOFER'S great A and great B. While still more recently M. CORNU in Paris, by an exceedingly elegant method of his own, having lately succeeded in eliminating from the α (Alpha) band of the same Solar spectrum, both the Solar metallic and the terrestrial water-vapour lines, found the residual markings so exactly the counterparts of the now thoroughly understood geometrical construction of the preliminary bands of great A and great B,—that he can pronounce with the utmost certainty for their being all three born of one and the same kind of gas; though whether, after all, that gas be really Oxygen, the world will be better instructed when other physicists have repeated the bizarre experiments of the Russian capital, and vouched for the purity of the gas introduced there into the long tube.

Even concerning Oxygen then, our knowledge is but rudimentary, and in fragments; while of Hydrogen, and Nitrogen, how very little have we yet seen of one, possibly two, of the three double phases which the temperature theory indicates must belong to every one of such permanent gases; and all of whose phases too, our observations in this paper promise will be found replete with the most exact Natural writing, whenever they be efficiently and sufficiently interrogated by man.

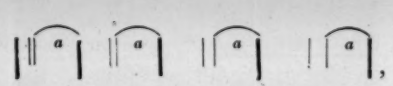
APPENDIX I.

PROF. ALEX. S. HERSCHEL'S LETTER ON THE GREEN BAND OF CO, AND ITS EXPLICATIONS (EVENTUALLY CONDENSED INTO PLATE LXXVIII.).

Dated November 20th, 1883; College of Science, Newcastle-on-Tyne.

The chart of the green band's lines* is beautiful; it is quite a page of the spectrum itself much more clearly laid down, I am sure, than I have ever seen the tribe of linelets, and I'm astonished how you can have both discovered and plotted so many perfectly!

You have far surpassed the sight you gave me last, I find, of the CO band, by dividing "broad" and plenty of the fine lines too, into pairs and triplets. This is a real triumph, that I couldn't well believe possible, when I discovered it by trying to recognise your new map in the drawing and measures that I took of SALLERON'S CO tube's *green band* (with five Sulphide of Carbon prisms) in December *last;* and couldn't make them fit immediately, until I found that you had duplicated and triplicated numbers of the lines that I recorded "broad," "winged," "united pair," &c., only, so that there is a profusion of new dissections of the band that you have managed now to supply for its anatomy! And then IO TRIUMPHE! in searching over the spaces of my "readings" to identify your lines with, I lighted luckily *on the key* of the construction, which is simplicity itself, and couldn't well be exceeded in the exactness with which your new map reveals it! *Lux in tenebris*, what a happy and glorious release you have disclosed to all our uncertainties!

I grounded first on this palpable feature of the measures 

that while the "leaders," and twin-cub followers open out regularly all down the range, it is not so between the twin-cubs and *the leader next following them*, so that the distances *a* remain constant, varying from 0·159 revns. to 0·172 revns. in my readings without any symptoms *of expanding*, as far as my list went; so that these "leaders" are simply accompanied *on the preceding side* by a companion pair that is at an invariable distance from them! In other words, the "leaders" form *a scale-in-chief* by *themselves*, and a little distance *preceding it* is just such another scale of fainter twins, overlying the former scale.

How will this relationship, I asked myself, be borne out *in the thronged part* of the band between its front edge and the "crossing" point, *beyond which* point as far as the "green giant," it is as plain as the alphabet?—The answer was to take up the constant distance *a* between any

* This was merely the raw record-slip taken at the Instrument, in the manner which I specially arranged for all the Spectra described in this paper.—C. P. S.

leader-line and its precursor shadow-pair from any good specimen conjunction of them on your map, and to apply it successively to all the leader lines from near the "green giant" backwards across the crossing-point and on into the thick of the mélée that precedes it, right up to the first edge of the band. The result was, to my joyful surprise that it *accounts instantly, and in toto for every* single line of the band laid down on your map! The band is *simply two exactly similar* single-rank line progressions laid over each other displacing one of them slightly on the other; and while one consists of single strong lines, the other is formed of fainter, closely double ones. You will see this by the enclosed card strips* along the top edge of one of which your map of the band *is exactly* copied, while under it the members that compose the close double, or fainter series are prolonged so as to produce a linelet progression by themselves. On another card the rest of the band's linelets are figured, also in a single-ray progression of (in red ink) strong single lines; by applying this card with its left hand leader *at No. 5 line* of the *natural* delineation, you will see that it includes all the lines *not* prolonged downwards or abstracted from that stripe to form the partial stripe of duplex lines; and by then shifting it leftwards till its beginning coincides with No. 1 line of the natural band, you will see too that it then exactly covers all the duplex line series of the natural band.

Besides the two constituent bands' precise resemblance to each other, there is also this link of connection between them, that the ruler of the following band is not placed *anywhere*, but ON *No. 5 line* of the foremost one. And again there is this simplicity about the single-rank or partial bands themselves, that their intervals are quite distinctly an arithmetical progression of spaces denoted by the series of natural numbers 1, 2, 3, 4, &c. I have plotted in, under each (singular and duplex) portion of the band *a true* simple progression of this kind, so that the eye can judge how nearly each of the two tributary bands satisfies it, and there is no question, I think that it is, with *some very slight* disturbances here and there, the simple rule of formation of them both? Instead of being, therefore, a linelet band of the most curiously involved *complexity*, as it at first sight looks by its "crossing" lines and close pack of crowded lines near the front edge, the ruled CO green band is really *the very simplest* in its mode of construction that I *think* has yet been met with in Spectroscopy! The way in which your sharp resolution of the two "crossings" lines themselves into a minute triplet and a minute doublet respectively agrees with the conjunction is by itself a wonderful corroboration of the structure. But without the clear and *precise* resolution *of all its lines throughout* with the most accurate autographic measurement that you have effected, it would evidently have been quite impossible to recognise and establish it in its microscopic mixture! A good example of the powerful discrimination that you have used upon the band occurs in its very first line, which I had noted "BROAD," only, in my little sketch of measurement, but which you have mapped as a pair Nos. 1 and 2 of the band, just as accurately placed as the other equivocal looking linelets of the band are all clearly and exactly broken up and divided into their proper places in the dual band.

The displacement between the band's two parts is 10 (1+2+3+4), unit spaces of the structure, which is neither an indifferent interval nor an indifferent number of unit-intervals of its structure; so that the two parts can't be described as two independent overlying bands belonging possibly to two different gases. But yet the *duality is* singular, as if either sever-

* These very ingenious card strips of Prof. HERSCHEL'S, being unsuited to book-illustration,—it occurred to me, to prepare Plate LXXVIII., including them both and the manner of working them, but in one statical view. This Plate afterwards had his approval, though with a *proviso* touching ideal accuracy, which he has touched on in Appendix II. page 43.—C. P. S.

ance into constituents physical, or constituents chemical, of the CO, was accomplished by the spark; and the tetravalence of Carbon *unsatiated by the* bivalence of Oxygen, or in other words the propriety that chemists admit (our chemical Professor, Dr BEDSON, just now suggests to me) of regarding Carbon as sometimes divalent like Oxygen in forming neutral combinations such as CO, may be the origin of (C(O)= =O O C O= =O O) the double structure

Tetravalent Carbon. Divalent Carbon.

of this CO linelet band. At any rate it will interest me very much to see if I can make better sense now, and trace some similar evidence, of duality perhaps in other "Carbon" records of the CO citron, and Blow-pipe-green Band-lines that I have, distinctly enough measured I daresay to tell the same tale if they are carefully interrogated.

A. S. H.

APPENDIX II.

PROF. ALEX. S. HERSCHEL'S LATER REMARKS ON PLATE LXXVIII., AND AN IMPROVABLE POINT IN ITS SCALE OF REPRESENTATION.—MAY, 1884.

Two distinct spectra closely resembling each other, together form the Green band of Carbonic oxide figured in the Plate LXXVIII.; one of which consists of single linelets, and the other of slowly opening double ones, or of linelets coupled together in close pairs. If the whole unilinear spectrum is shifted together to the left until its first line coincides with the leading one at the band's least refrangible edge, all its lines fall nearly into coincidence either with the middle place, or else with one or other side-line of the several linelet pairs of which the remaining bilinear portion of the spectrum is composed.

An ideal spectrum is placed for comparison above and below the two component spectra of the band, forming an arithmetical series of micrometer-revolution, or of sensible dispersion intervals, representing with a suitable scale-unit of measurement, the series of natural numbers 1, 2, 3, 4, &c. The necessary data for replacing this array of gradually increasing micrometrical intervals by a similar, more scientific arithmetrical progression having a wave-number unit instead of a micrometrical dispersion one for prime measure of its successive terms or intervals, was not exactly procurable in the state of the instrument's adjustment; but the small regular differences which are noticeable in the Plate between the two observed spectra and the arithmetical comparison series of micrometrical line intervals, are, it may be remarked, of exactly the description in direction and in varying magnitude which the provisional substitution in the Plate of a micrometrical for a wave-number series of successive intervals would correspond to, and serves sufficiently to account for. Were such a replacement of the provisional array by a corresponding wave-number one made with perfect certainty and correctness, it would seem to be a safely legitimate assumption to conclude, that the small visible departures of the ideal from the observed spectra which their comparison together exhibits on the Plate, would all, then, be quite satisfactorily obliterated and removed.

A. S. H.

To which I, as the Observer, may probably be allowed to add,—*not "quite removed."* For wherever there is numerical observation aiming at exactness, there will always be errors of the observer to some extent. But I must confess I have been well pleased to see the *smaller* amount of the apparent errors of observation, when one Natural System of spectral lines is compared with another, as in the lowest compartment of Plate ;—than when either one of them is contrasted with the artificial screw-unit scale, as shown *first* at the top of the plate, and then near the bottom of it; viz., Plate LXXVIII.—C. P. S.

APPENDIX III.

MR CHARLES F. CASELLA'S LETTERS ON THE PREPARATION AND PURIFICATION OF SOME OF HIS LATER VACUUM TUBES.

147 HOLBORN, LONDON, E.C.,
31*st August* 1883.

To Professor C. Piazzi Smyth, F.R.S.E,
15 Royal Terrace, Edinburgh.

DEAR SIR,—I am in due receipt of your favour of the 30th inst., and I must thank you for the kind expressions that you make use of with regard to my Father, as well as for your kindness in communicating with me on the subject of the Tubes.

By train to-day I have great pleasure in sending you three tubes, viz., the 4th $CO+CO^2$ Tube at 0·2″ pressure, and the $CO+CO^2$ Tube at 0·3″ pressure, also the N tube at 12·5″ pressure—all of which I trust will be entirely to your satisfaction.

This now completes all the Tubes I have had to do for you, and I now beg to give you a formal note of how the gases in the above tubes have been made, the various processes being as follows.

Hydrogen, by electrolysis of water. Oxygen I tried as above, but the manufacture of the gas was so dreadfully slow, that I had to resort to a chemical process, viz., by heating chlorate of Potass, which I think is the most satisfactory way of obtaining Oxygen.

Nitrogen, by boiling Ammonium Nitrate; of course the preliminary bubblings yielding impure Nitrogen, were allowed to escape, and only the subsequent bubbles of gas collected. Carbonic Acid, by heating ferro-cyanide of Potassium with eight times its weight of sulphuric acid.

Coal-gas simply by connecting the gas jet with the gas receiver connected to the Pump.

$CO+CO^2$ prepared by heating crystallised oxalic acid with concentrated sulphuric acid.

All the above gases were prepared in glass retorts, then passed through water into glass receiver, which latter was connected with the Pump by glass tubes, and a very delicate small steel tap; the various drying tubes used were—next to the end-on tube a Caustic Potass tube; immediately next to which was an Anhydrous Phosphoric acid tube: then came a four-foot pummice-stone tube saturated with concentrated sulphuric acid; next to which was a small chloride of Calcium tube, and then came the small steel tap separating the Pump from the gas receiver. Before making each gas the trough, receiver, and everything were thoroughly cleaned, and fresh water and new drying tubes used each time; a new Phosphoric Acid tube being used for each tube.

I trust I have made myself clear in all the above details, but if I have not, pray do not hesitate to ask me for further particulars.

Assuring you of best attention at all times, and hoping that at some time I may have the honour of being specially mentioned in connection with the preparation of these tubes, which

I confess require the greatest personal thought and attention.—I am, dear Sir, yours very truly, CHARLES F. CASELLA.

P.S.—Your note of the 31st just to hand. I will carry out your suggestion by using naked copper wires instead of gutta-percha covered ones, which already are suspended across my laboratory with a pair of leads coming down to each Pump.

Before doing so, however, may I have your opinion on the following suggestion in opposition to yours, namely, the various strong and damp fumes the naked wires would be subjected to, would create a strong oxidation on them, and would not therefore the current, instead of conveying one gas into the tubes, which gas we already are acquainted with, carry a variety of "gaseous" all sorts into our tubes.

This is a mere hypothesis of mine, and therefore please take it for what it is worth.

C. F. C.

LONDON, E.C., 13*th Nov.* 1883.

DEAR SIR,—Your favour of the 9th inst. has duly reached me, and I have now much pleasure in telling you that I am back again in office, having returned last week.

Before being able to say that I am ready to commence vacuum tube work again, I must tell you that my pump room or laboratory is without pumps, they having all become spoilt and broken by wear and tear.

To make fresh ones will take about two or three weeks, they being very elaborate but exquisite instruments.

Please state how many olefiant and acetylene tubes and at what pressure you would like.

I will note all my chemical proceedings, and also let you have an account of those last sent, which is as follows, viz.:—Action of Nitric Acid on pure copper filings (turnings), gas collected in a receiver in water, and communication from receiver to pump, the gas first passing through four drying tubes as follows, viz.—(1) Chloride Calcium, (2) Anhydride Phosphoric Acid, (3) Anhydride Phosphoric Acid, (4) Caustic Potash. Minor details, &c., were conducted as before, but with the same care in every respect.—Yours truly,

CHARLES F. CASELLA.

Previous to these chemical operations of Mr C. F. CASELLA, his father, Mr LOUIS P. CASELLA, had had some curious experiences with the wires forming the electrodes of his vacuum tubes.

Platinum wires usually blacked the inside of the bulbs; wherefore he then tried gold,—the following recommendation of that metal in the *Proceedings* of the Royal Society, London (and subsequently reprinted in the *Philosophical Transactions*, Part I., for 1884, page 51), having been brought to his notice:—

"Of all *metals* affording materials for electrodes, gold appears to be the best; its spectrum is a weak one, containing comparatively few lines; it is an excellent conductor of electricity, and it is not attacked by solutions of metallic chlorides."

No sooner, however, did he try this highly commended material than the insides of his tubes were brilliantly, opakely, and utterly gilt by *it*, combined with the six-inch induction sparks employed. He had, therefore, to fall back on aluminium wire and to use that very thick, or between $\frac{1}{16}$ and $\frac{1}{12}$ inch in diameter. C. P. S.

APPENDIX IV.

SEE THE THIRTY-ONE PLATES, FOLLOWING AFTER THE PRINTED MATTER.

Viz. 29 Plates, each opening to 18 × 11 inches, and showing what they contain on a 40 foot spectrum length from A to H;

1 Plate, folding out to 42 × 11 inches, giving approximate and contracted views only, of whole spectra, 26 inches long from A to H;

And 1 Plate, folding out also to 42 × 11 inches; but showing what it contains on a spectrum length of 220 feet from A to H; a length erroneously printed in earlier pages herein as 120 feet only.

APPENDIX V.

ON THE NUMERICAL "WAVE-NUMBER" SPECTRUM SCALE OF ALL THE PLATES.

The regularly altering number of theoretical Waves of Light at each part of the spectrum, contained in a certain constant unit of length, and called for shortness "Wave-number," has been adopted here, rather than the successive lengths of each of such waves, or "Wave-length," as a practical scale for each of our spectrum pictures—because it gives a most desirable mean between the oppositely exaggerated views of Prisms on one side, and Gratings on the other. And the Inch was at the same time employed as the unit of absolute length referred to, because it is not only British, but nearly Earth-commensurable in the best way; viz., as the 500 millionth of the length of the Earth's Axis of Rotation; and it furnishes also a convenient series of numbers for the memory.

The method is, moreover, in the direction of its increase of figures, combined with the universal European mode of writing from left to right,—exactly suitable to Fraunhofer's now nexpugnable order of *lettering* the chief lines of the Solar spectrum from Red A as the beginning, to Violet H as the end; or from lowest to highest, or Earthly ordinary, to Solar transcendental, temperatures. Hence "Wave-number" always goes conformably from Fraunhofer's A to his B, C, &c., and from his so-called b^1 to his b^2, b^3, &c. While the "Wave-length" method, with its reversed numbers, leads the Spectroscopists who adopt it—whether in terms of French or English measures of length—to do despite to the memory of their great predecessor by going backwards with his letters, while forwards with their own numbers; or by beginning the visible spectrum with H and ending it with A, in a manner so confusing to the rest of the world, accustomed long since to invariable procedure from A to H; and also from b^1 to b^4, in place of the opposite arrangement so recently introduced by the French metricalists.

C. P. S.

ERRATA.

P. 416, line 29; p. 420, line 19; p. 420, line 12 *ab imo*; p. 421, line 20; p. 442, line 19; and back of Plate lxxvi. line 4 *ab imo*, *for* 120, *read* 220, foot spectrum length *passim*.

P. 442, line 12, *for* frebling *read* trebling.

P. 443, line 9, *for* bright-lines pectra, *read* bright-line spectra.

P. 443, line 21, *for* spectrescope *read* spectroscope.

P. 447, footnote, *erase* the latter half.

TITLE PAGE TO THE PLATES OF

MICROMETRICAL MEASURES OF GASEOUS SPECTRA

GENERAL RULES FOR THE METHOD OF REPRESENTATION ADOPTED IN THESE PLATES.

(1) The Method is Negative, in that Light is represented by Black, and Darkness by White.

(2) Every straight Vertical Line, whether thick or thin, and whether close to another or not, within the limits of each horizontal Spectrum Strip, always stands for a veritable and measured Spectroscopic Line, or monochromatic image of the Slit; and nothing else.

(3) Lines in any other direction than Vertical, i.e., *whether horizontal or slanting, and from either side, or both sides at once as in crossed lines, also wavy lines,—are to be interpreted as Nebulous Shade only, in vertical bars or bands of corresponding width at the place.*

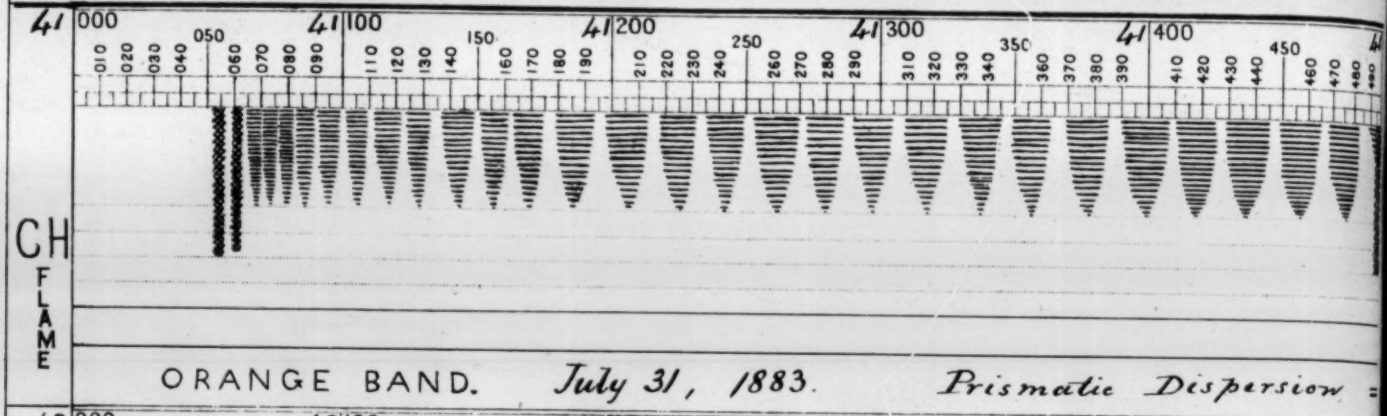
(4) Greater or less Height or Depth, either of Lines or Bands,—is intended, in connection with the amount of ink expended upon them, to typify greater or less intensity and visibility of such Lines or Bands.

(5) Cones of shade arranged on a vertical central axis, indicate nebulous bands of pale light, shaded off towards either side very gradually and delicately.

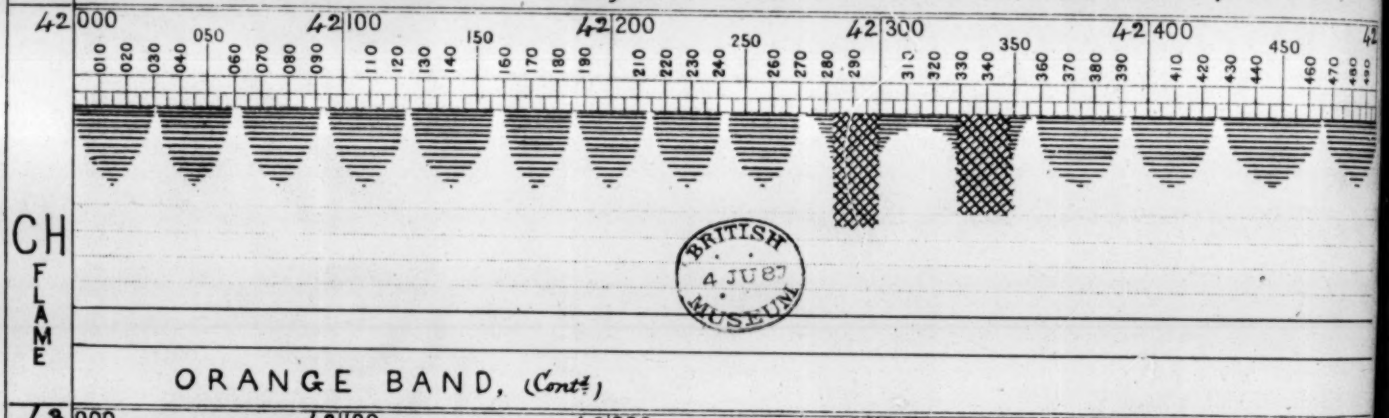
C. P. S.

S. ubs & del. 1. A. Ritchie & Son. Photo-Lith. 1884.

CH IN BLOW-

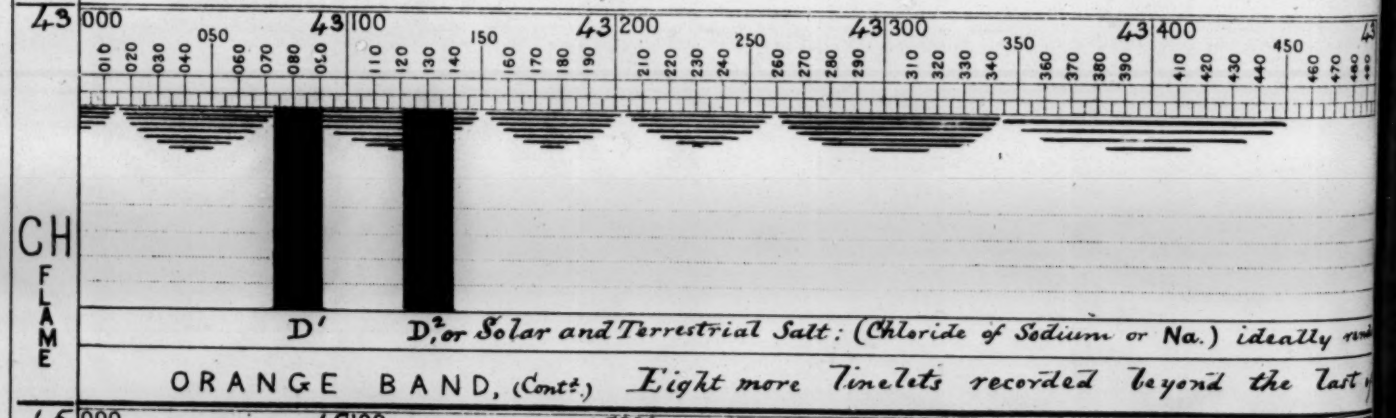


ORANGE BAND. *July 31, 1883.* *Prismatic Dispersion =*



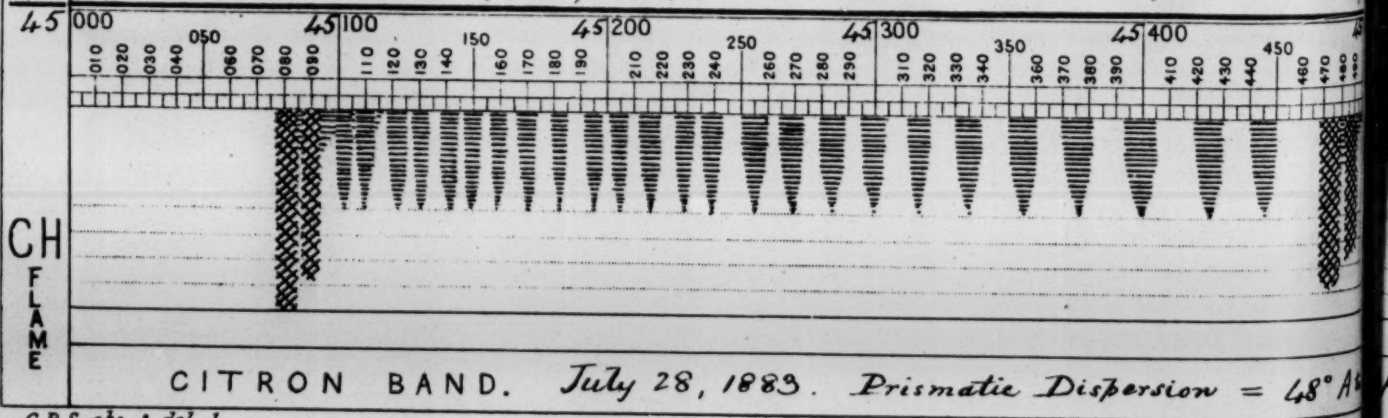
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ORANGE BAND, (*Cont^d.*)



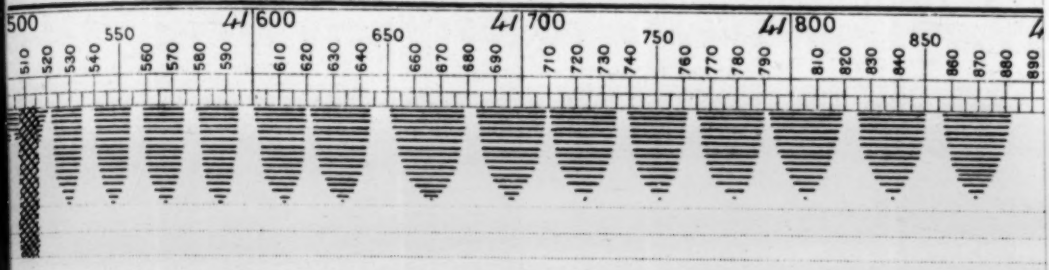
D′ D², or Solar and Terrestrial Salt: (Chloride of Sodium or Na.) ideally

ORANGE BAND, (*Cont^d.*) *Eight more lineletts recorded beyond the last*

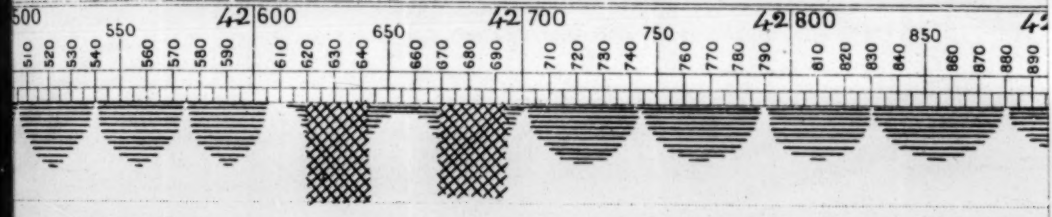


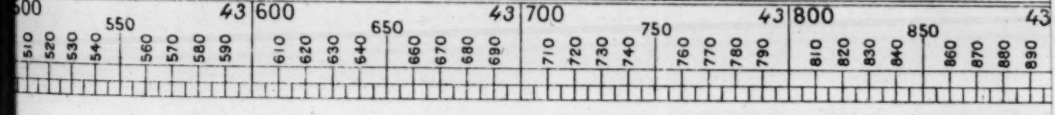
CITRON BAND. *July 28, 1883.* *Prismatic Dispersion = 48° A*

PIPE FLAME



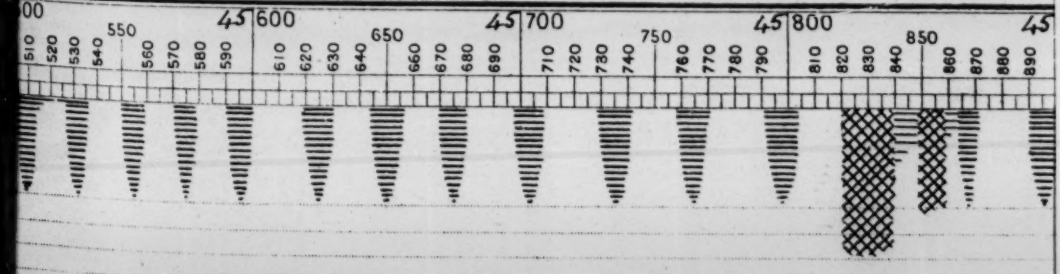
37° A to H. The view very faint, diffuse and hazy.





red to show by contrast the faint, gauzy, airy, open, granular character of the gray Bl

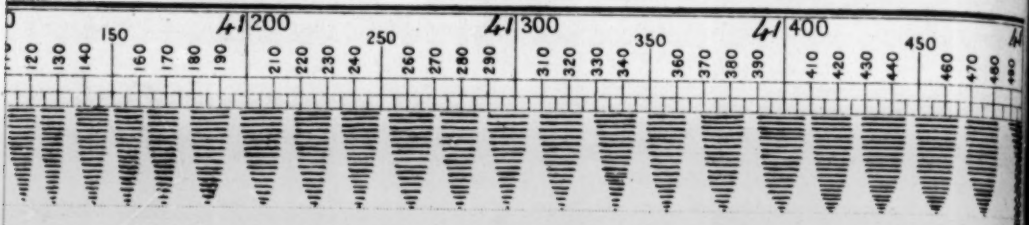
these, always increasing in breadth and confluent faintness



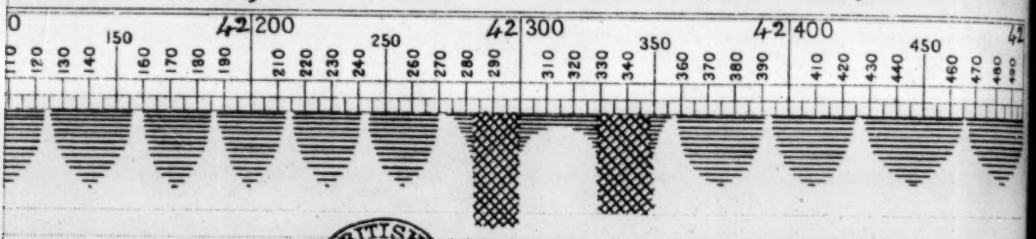
H. Lines and linelets far clearer and stronger than in

Photo-lith. 1884.

CH IN BLOW

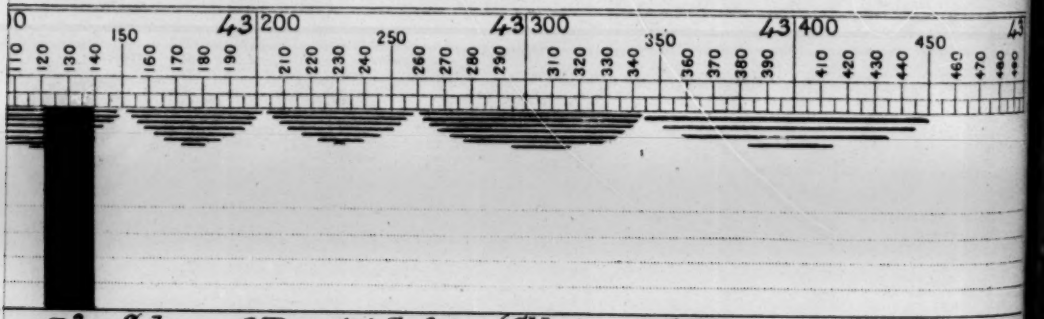


BAND. *July 31, 1883.* *Prismatic Dispersion =*



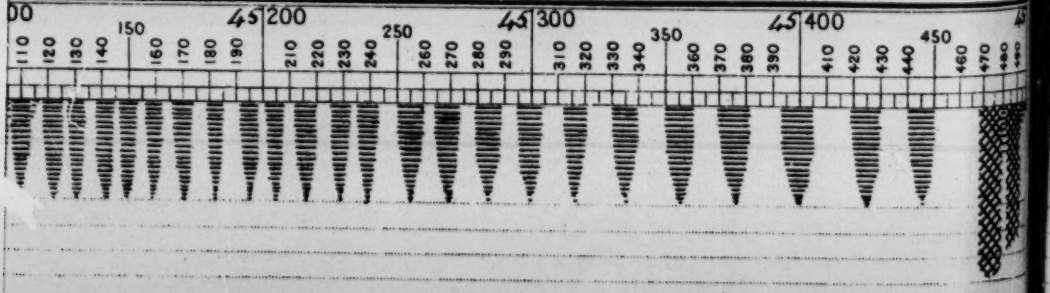
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BAND, (Cont.)



D², or Solar and Terrestrial Salt: (Chloride of Sodium or Na.) ideally vis

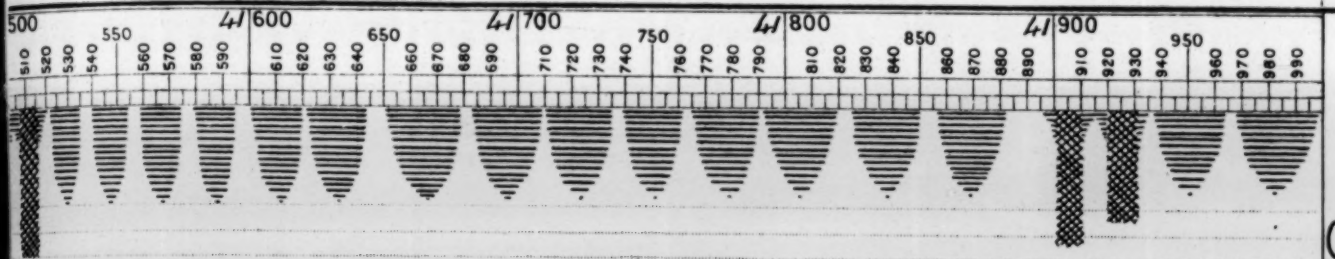
BAND, (Cont.) *Eight more linelets recorded beyond the last*



BAND. *July 28, 1883.* *Prismatic Dispersion = 48° A*

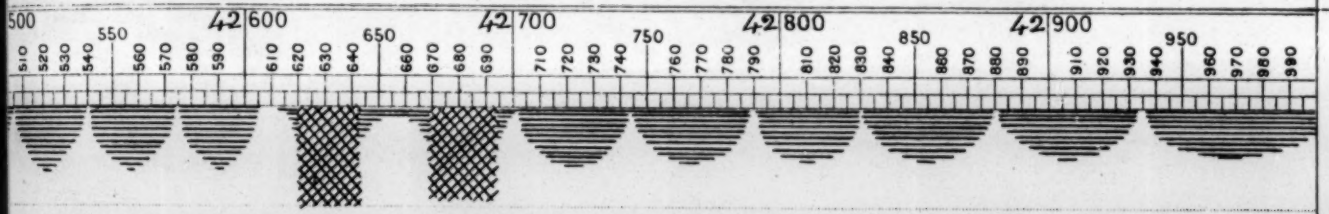
A. Ritchie & Son, Photo-lith

PIPE FLAME.

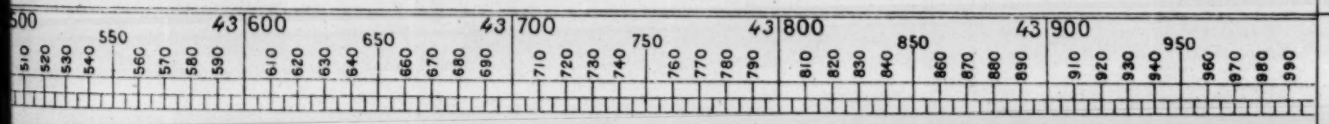


CH FLAME

37° A to H. The view very faint, diffuse and hazy.



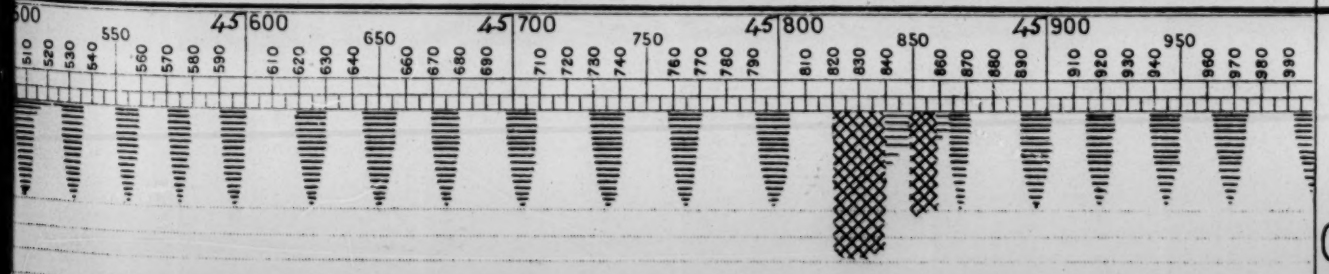
CH FLAME



CH FLAME

ried to show by contrast the faint, gauzy, airy, open, granular character of the gray Blow-pipe light.

these, always increasing in breadth and confluent faintness of haze.

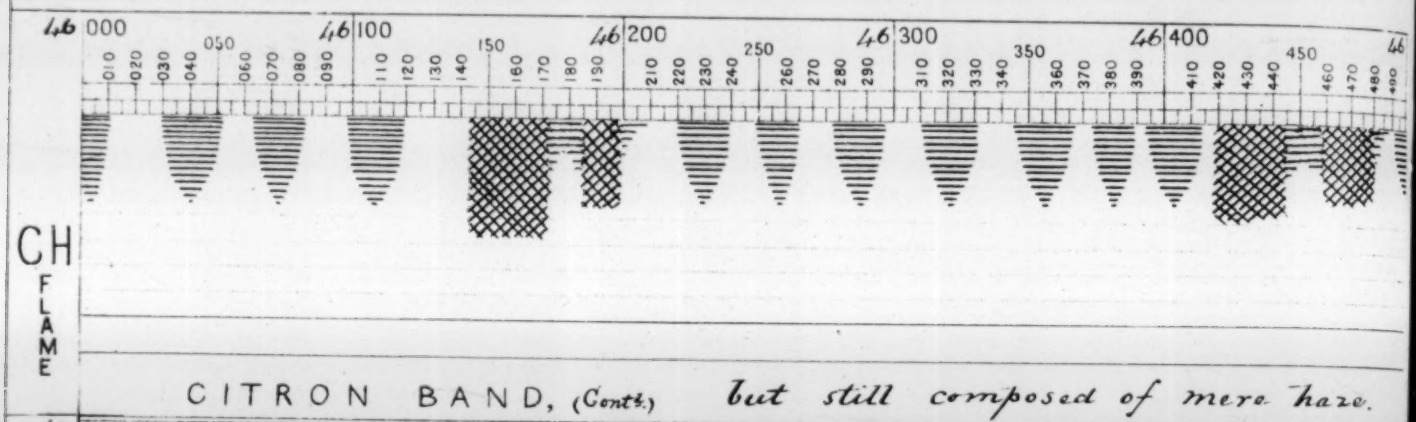


CH FLAME

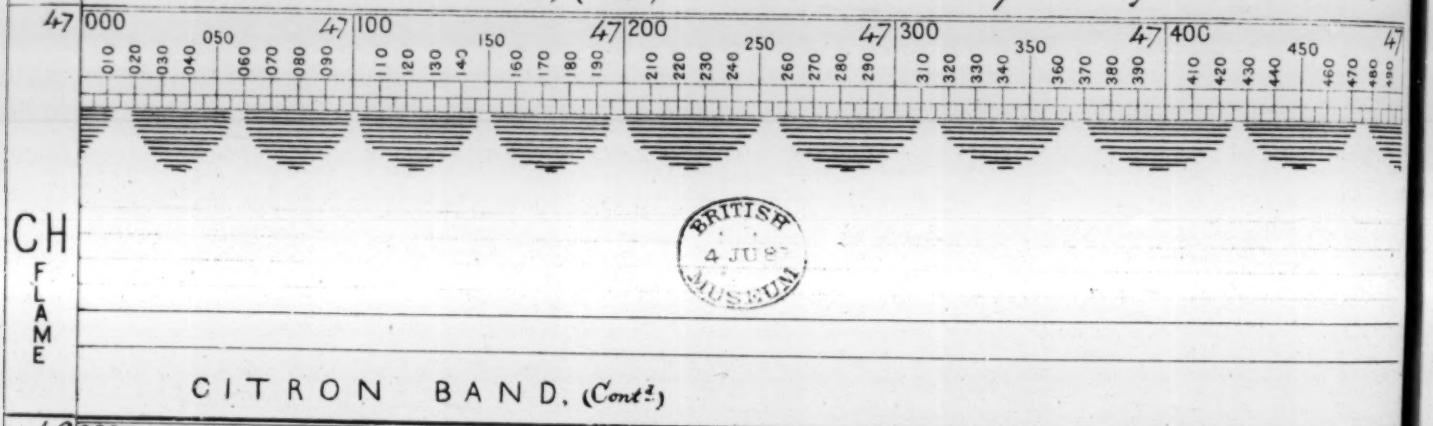
H. Lines and linelets far clearer and stronger than in Orange band,

Photo-lith. 1884. T.H. del. 2.

CH IN BLOW-

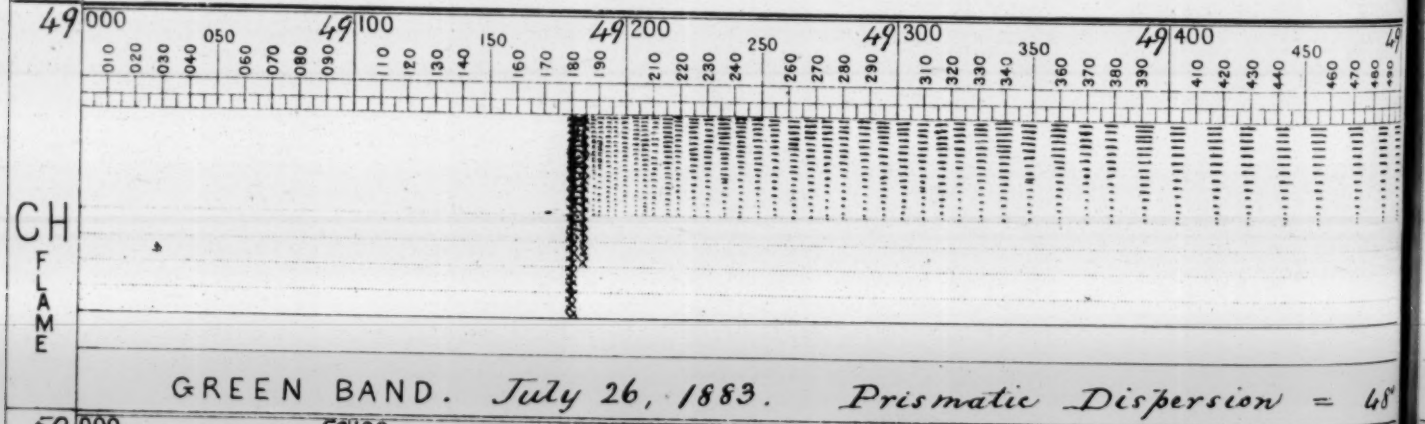


CITRON BAND, (Cont.) but still composed of mere haze.

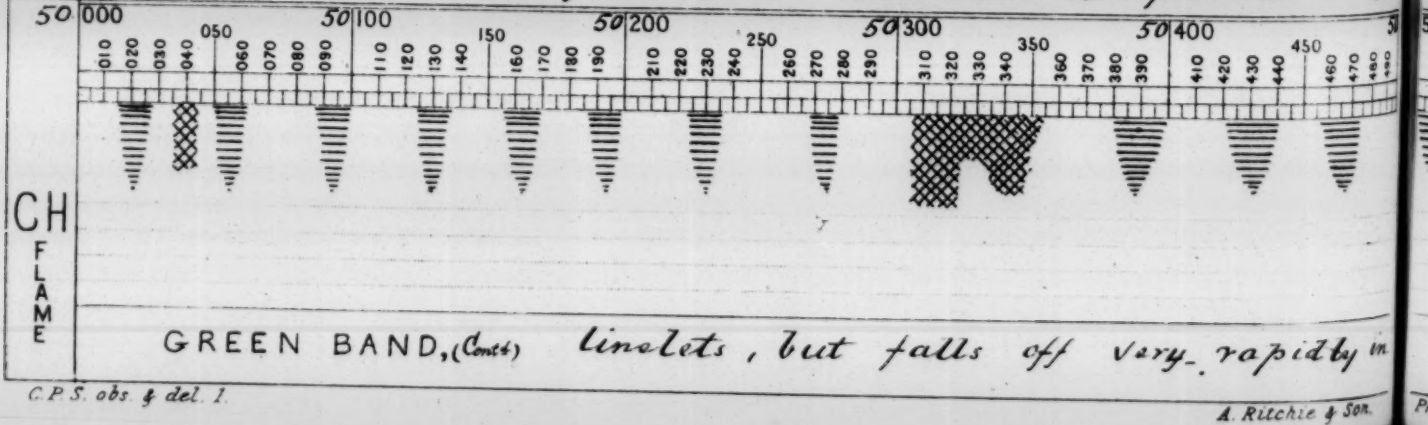


BRITISH MUSEUM 4 JUL

CITRON BAND. (Cont.)

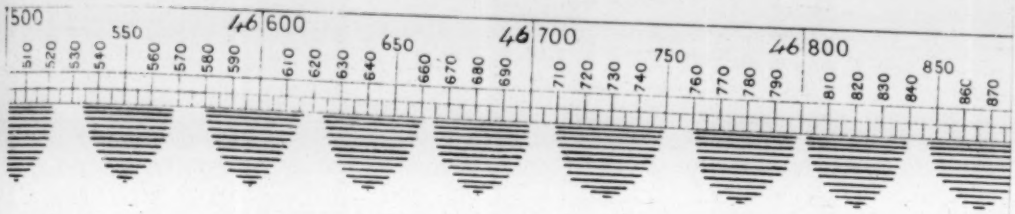


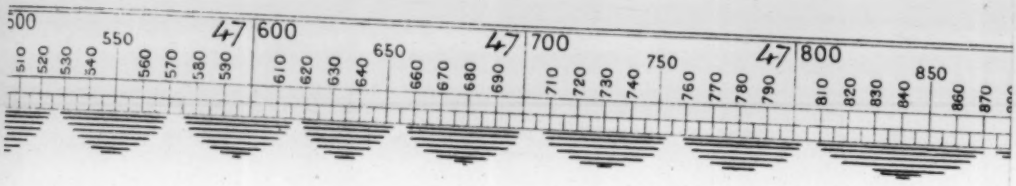
GREEN BAND. July 26, 1883. Prismatic Dispersion = 48

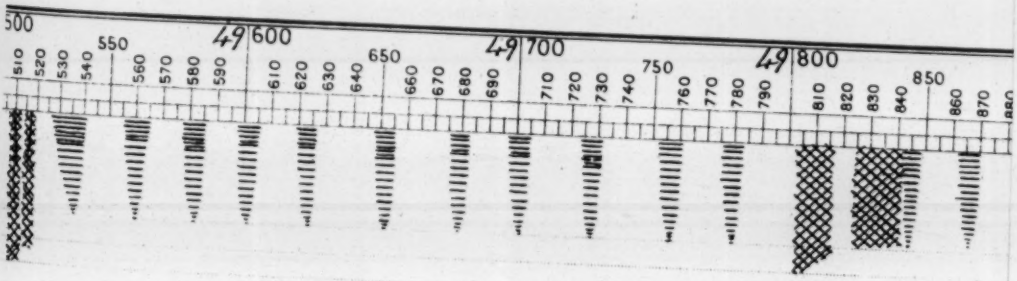


GREEN BAND, (Cont.) linelets, but falls off very rapidly in

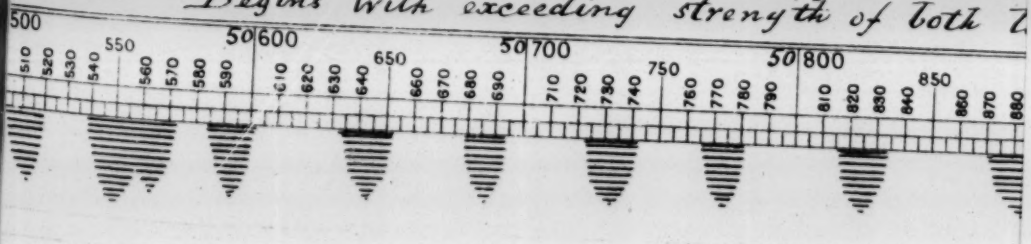
-PIPE FLAME







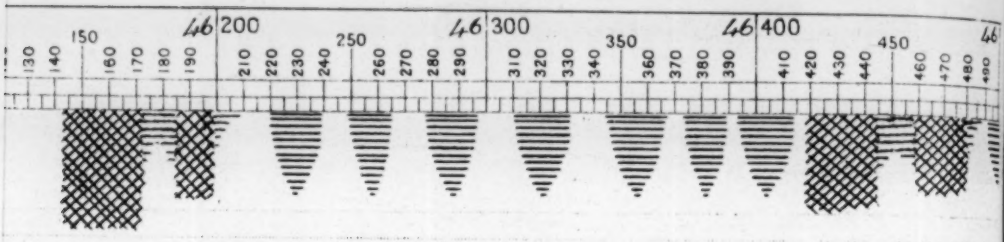
A to H. Begins with exceeding strength of both T



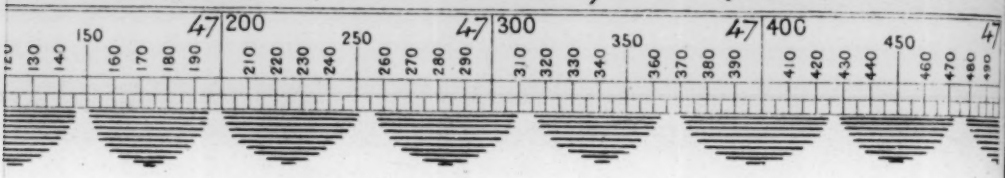
intensity The leading line of all, at 49 180 W.M

Photo-Lith. 1884.

CH IN BLOW-

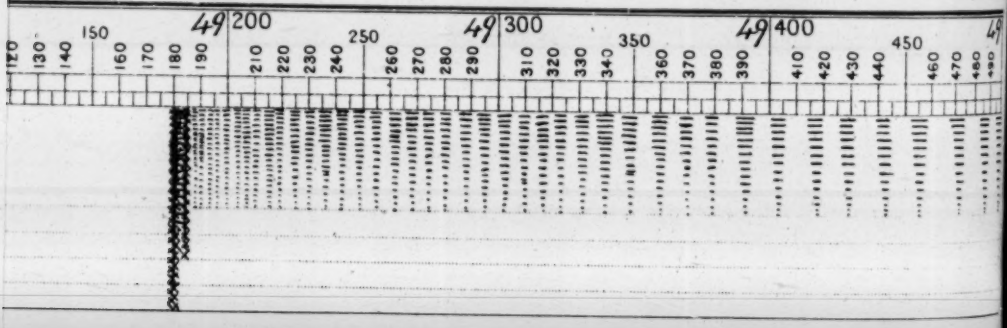


BAND, (Cont.) but still composed of mere haze.

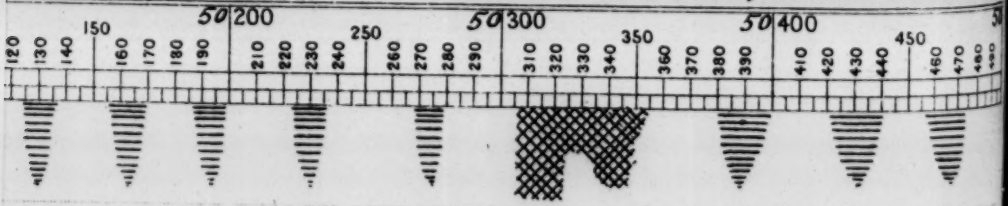


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MUSEUM

BAND. (Cont.)

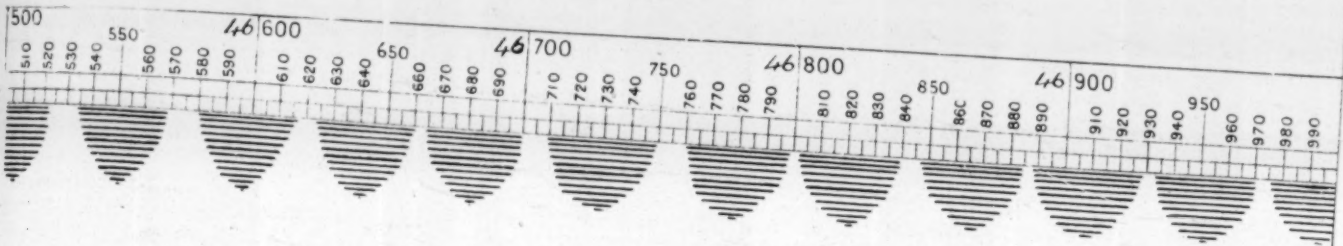


ID. July 26, 1883. Prismatic Dispersion = 48°

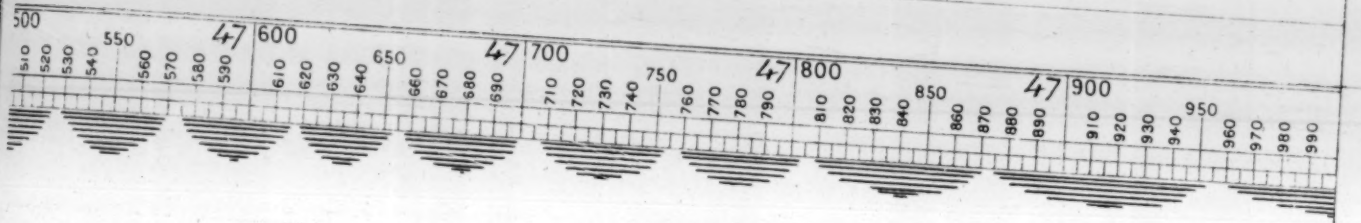


ND, (Cont.) linelets, but falls off very rapidly in

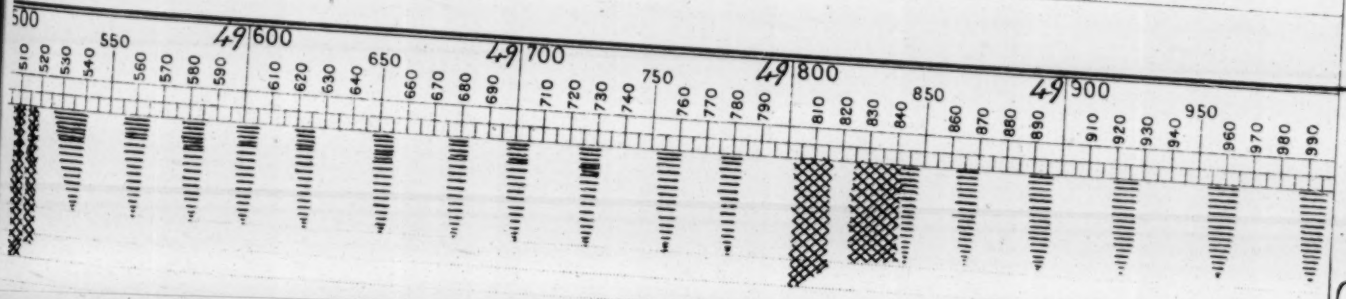
-PIPE FLAME



CH FLAME



CH FLAME



CH FLAME



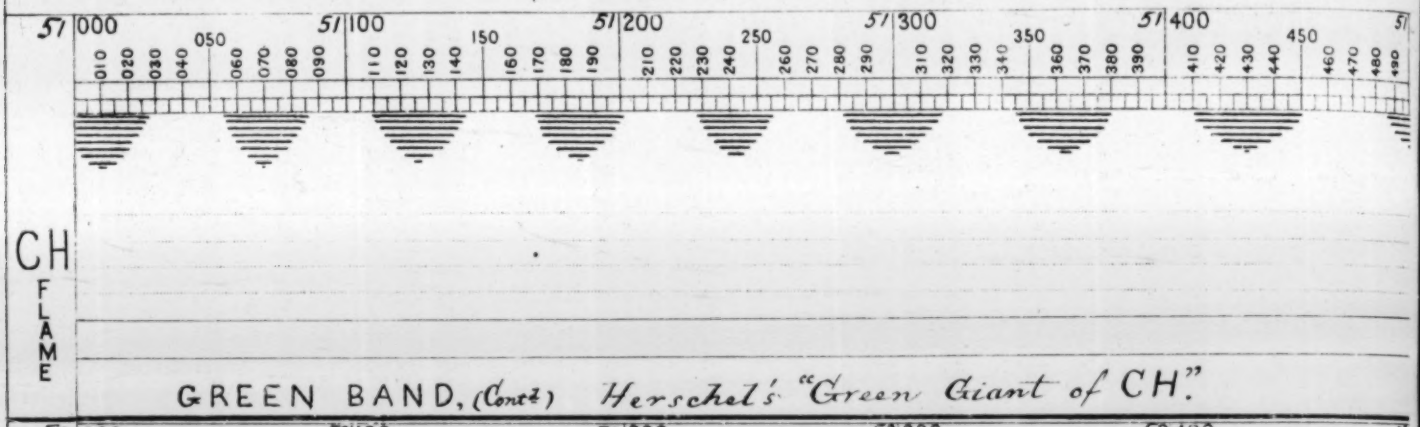
CH FLAME

A to H. Begins with exceeding strength of both lines and intensity The leading line of all, at 49 180 W.N. is Prof. Alex.

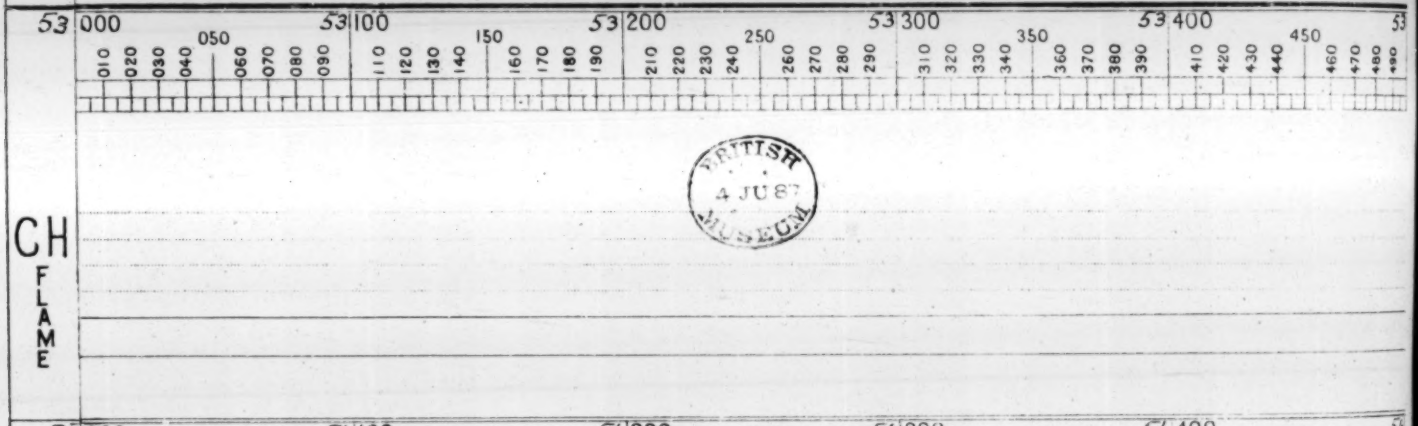
Photo-Lith. 1884.

T.H. del 2.

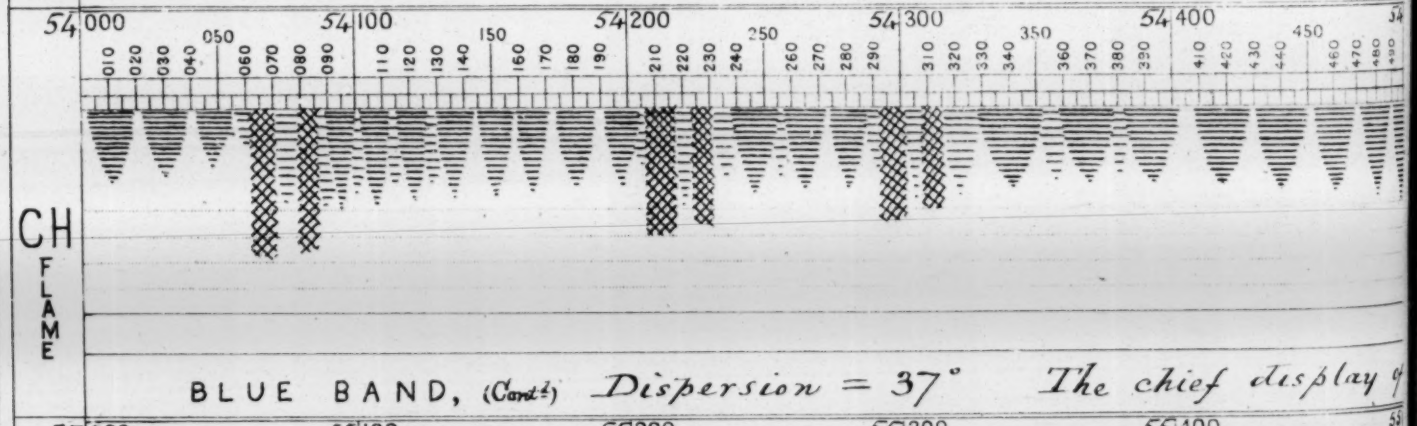
CH IN BLOW-



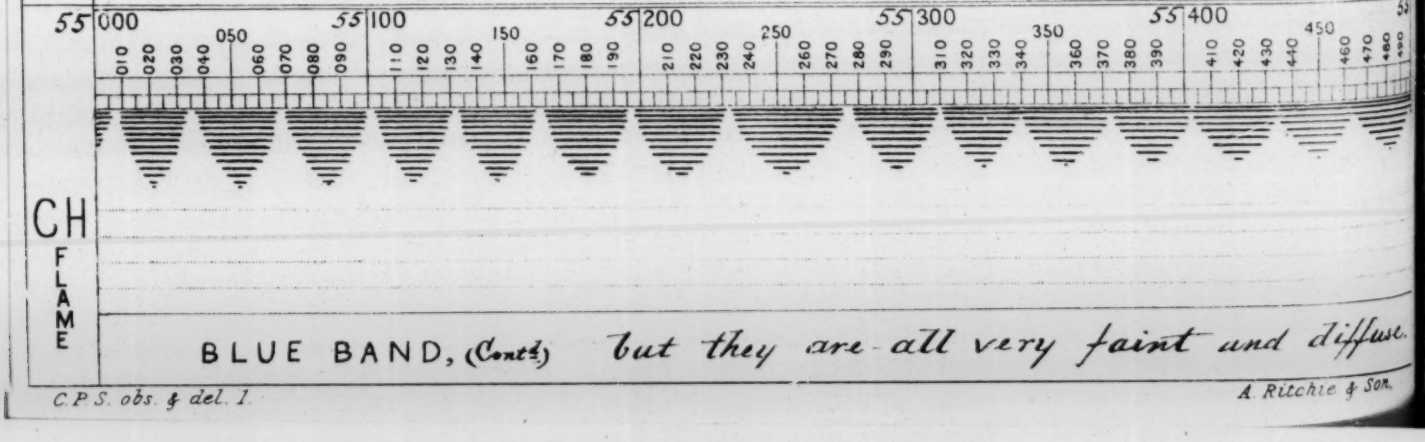
GREEN BAND, (Cont^{d}) *Herschel's "Green Giant of CH".*



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BLUE BAND, (Cont^{d}) *Dispersion = 37° The chief display of*

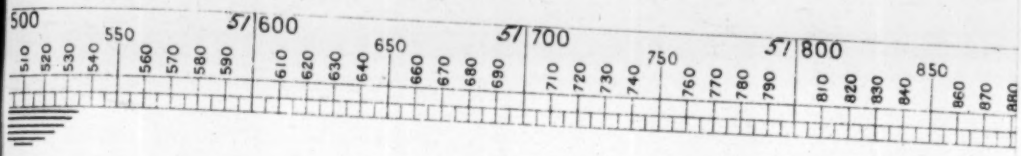


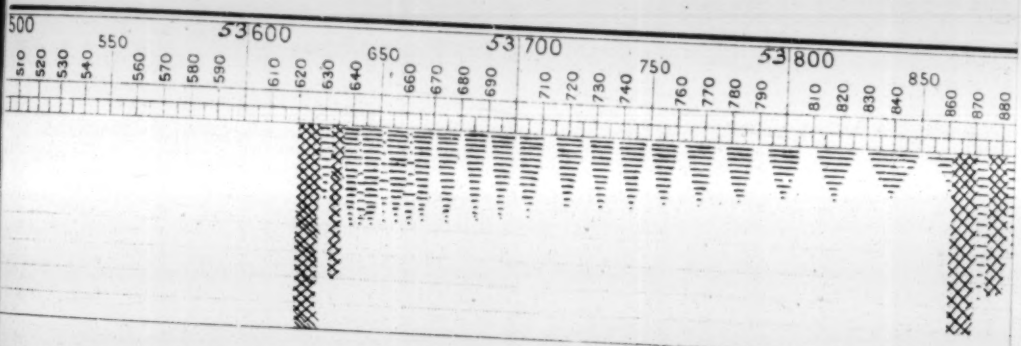
BLUE BAND, (Cont^{d}) *but they are all very faint and diffuse.*

C.P.S. obs. & del. 1.

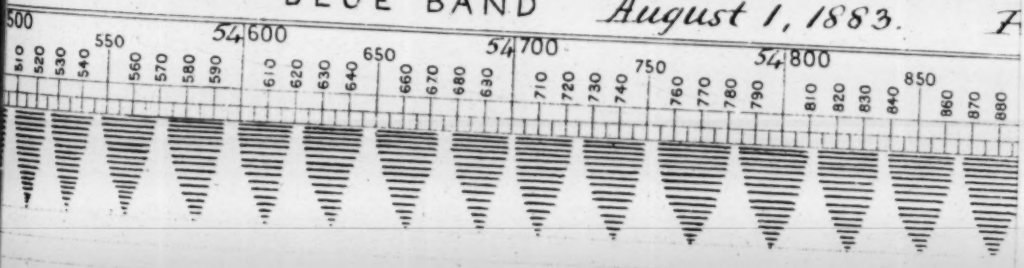
A. Ritchie & Son.

-PIPE FLAME





BLUE BAND *August 1, 1883.*



lunelets is altogether beyond the region of the

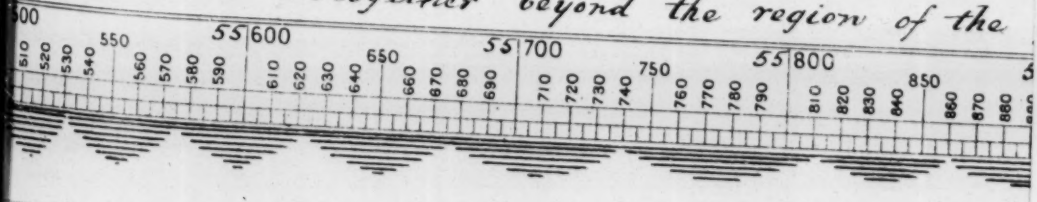
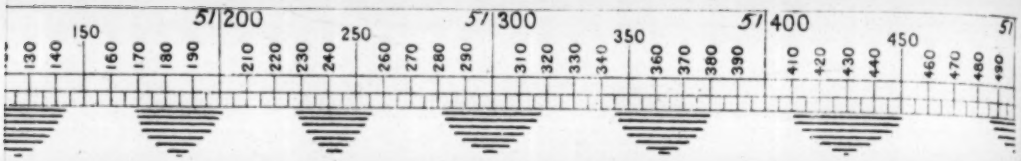
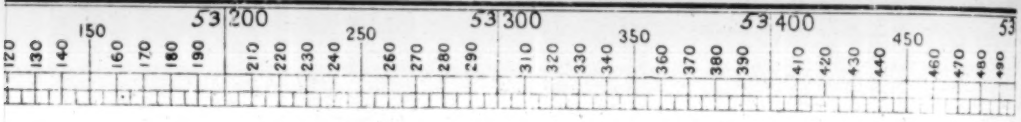


Photo-Lith. 1884.

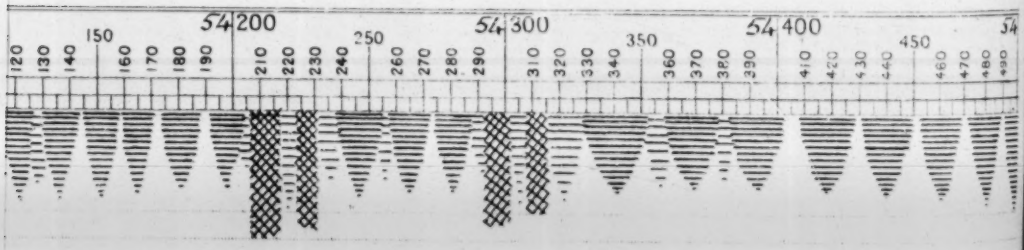
CH IN BLOW-



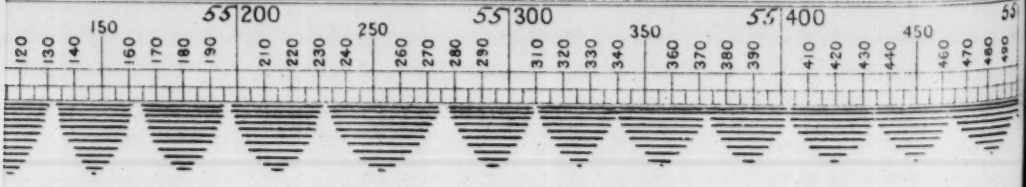
ND, (Cont.) Herschel's "Green Giant of CH".



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ND, (Cont.) Dispersion = 37° The chief display of



ID, (Cont.) but they are all very faint and diffuse.

A. Ritchie & Son.

-PIPE FLAME

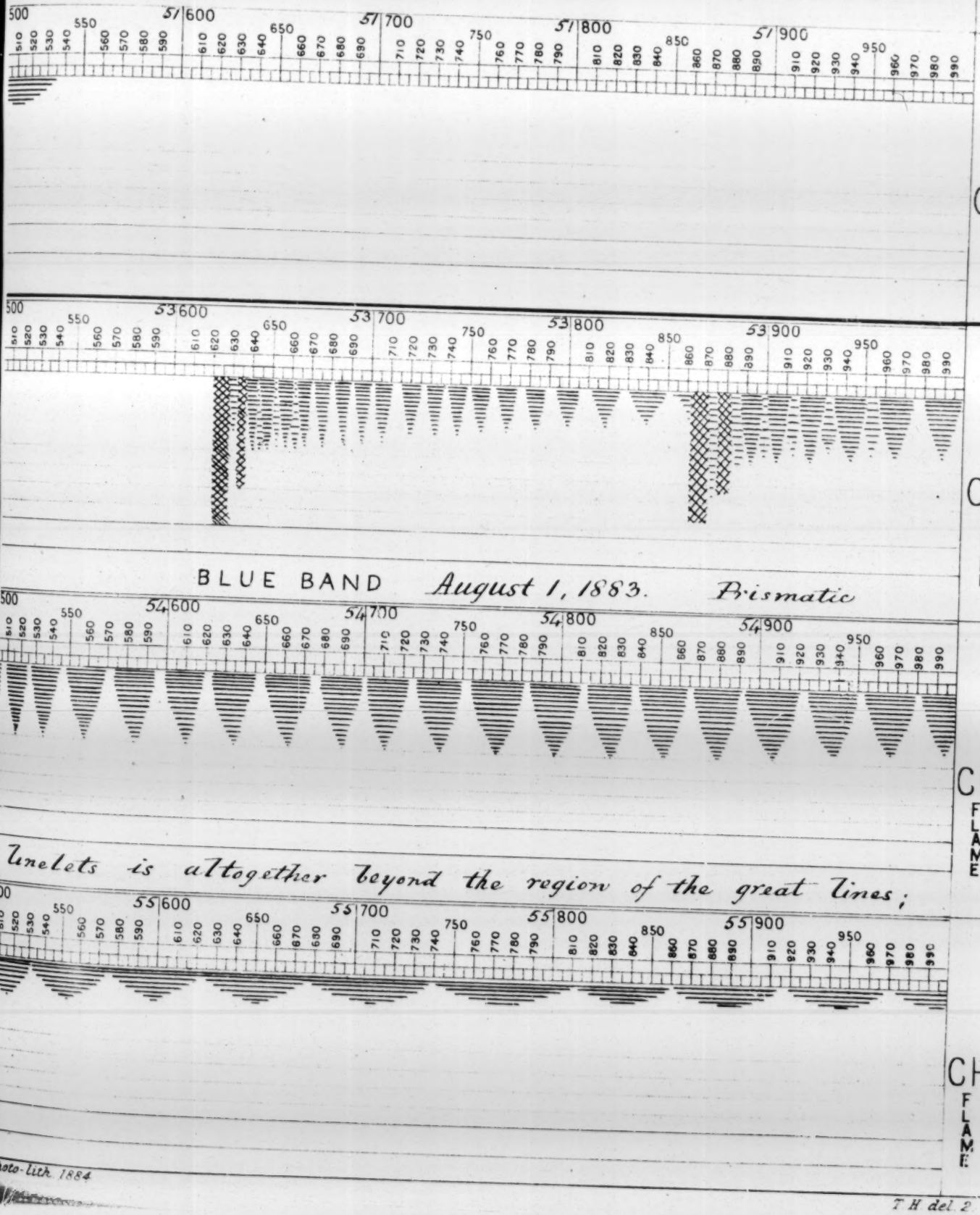
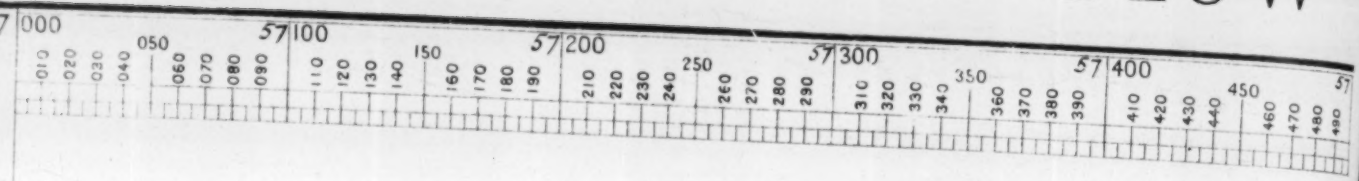


Photo-Lith. 1884

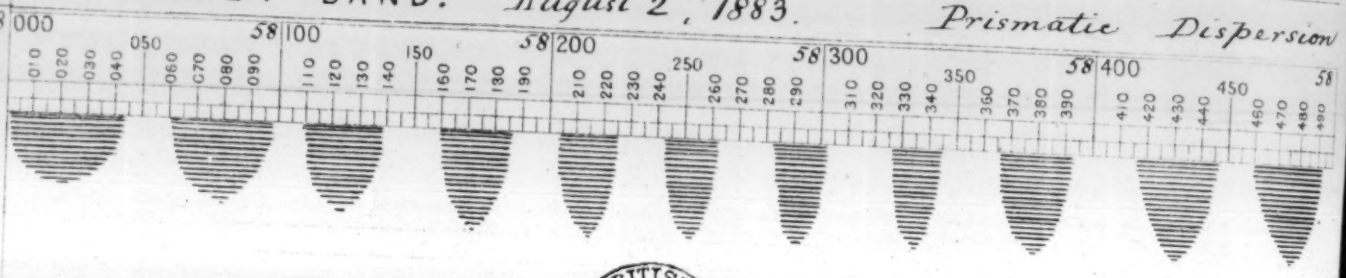
T H del 2

CH IN BLOW-



CH FLAME

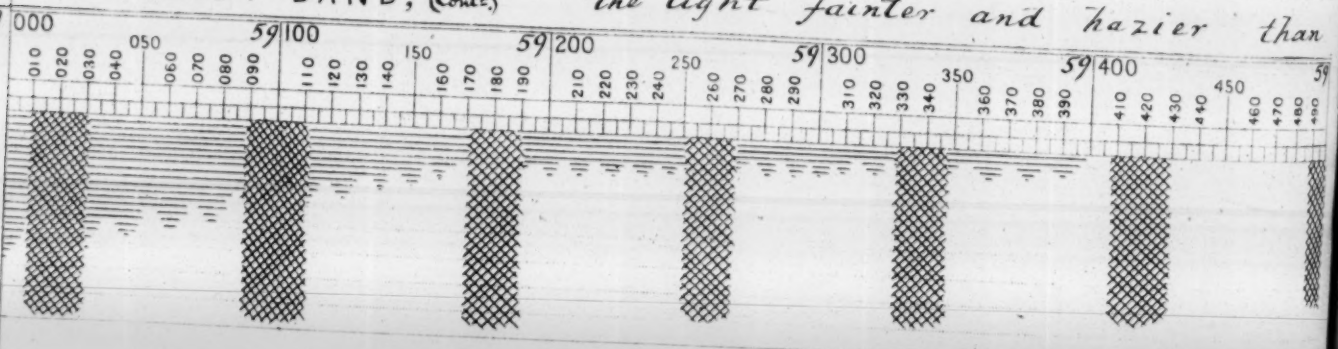
VIOLET BAND. August 2, 1883. Prismatic Dispersion



CH FLAME

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VIOLET BAND, (Contd.) the light fainter and hazier than



CH FLAME

VIOLET BAND, (Contd.) very notable band taken altogether

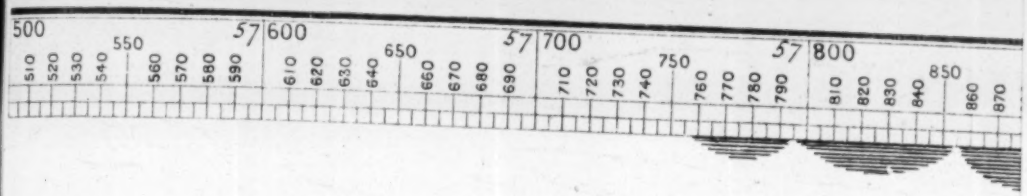
CH FLAME

C.P.S. obs & del. 1

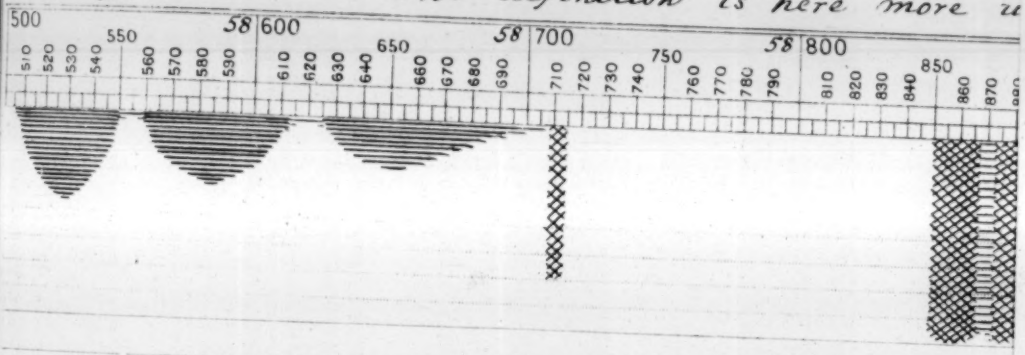
A. Ritchie & Son.

Photo-lit

V - - PIPE FLAME



= 37° A to H The definition is here more u



anywhere else ; but there is so much of it as

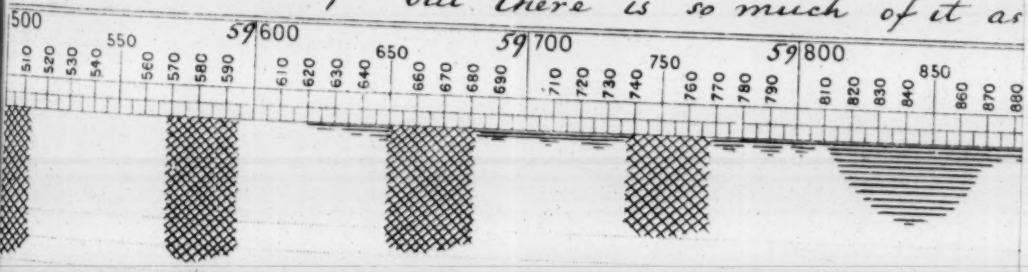
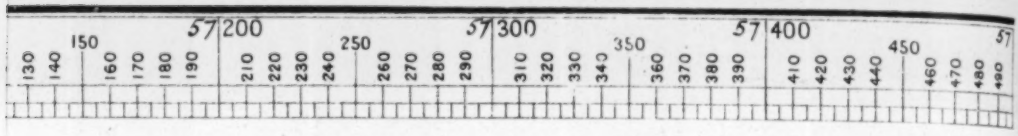
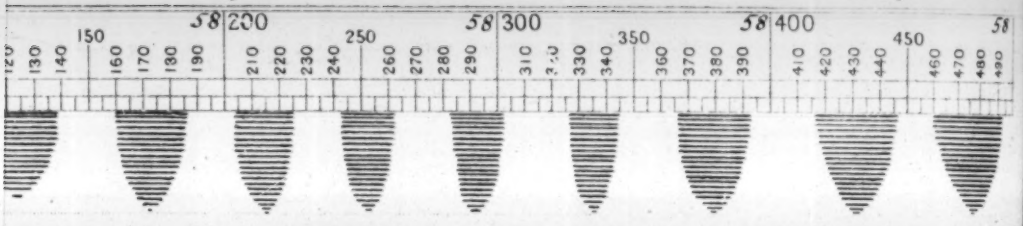


Photo-Lith. 1884.

CH IN BLOW-

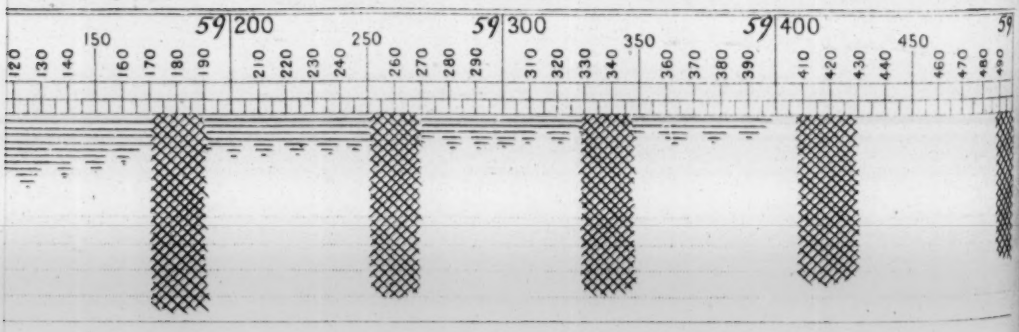


AND. *August 2, 1883.* *Prismatic Dispersion*



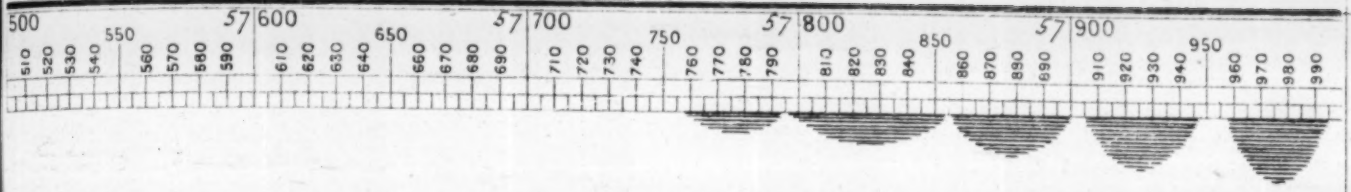
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AND, (Contd.) *the light fainter and hazier than*



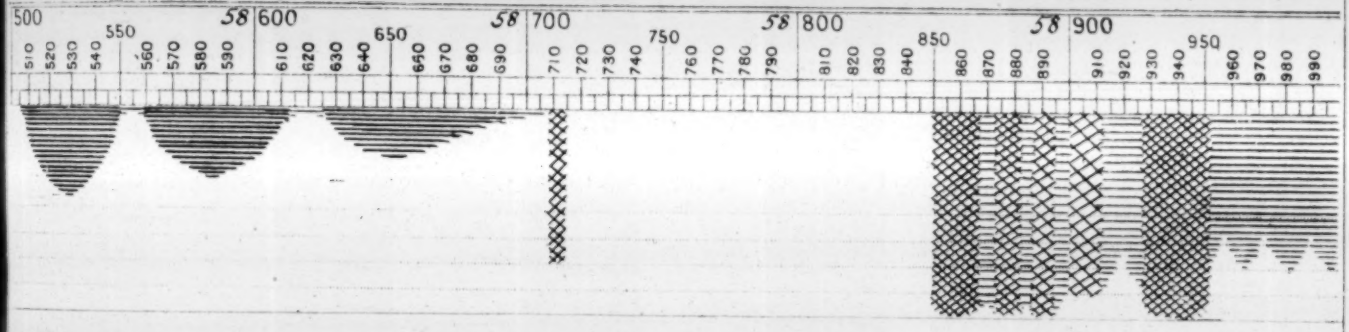
BAND, (Contd.) *very notable band taken altogether.*

- PIPE FLAME



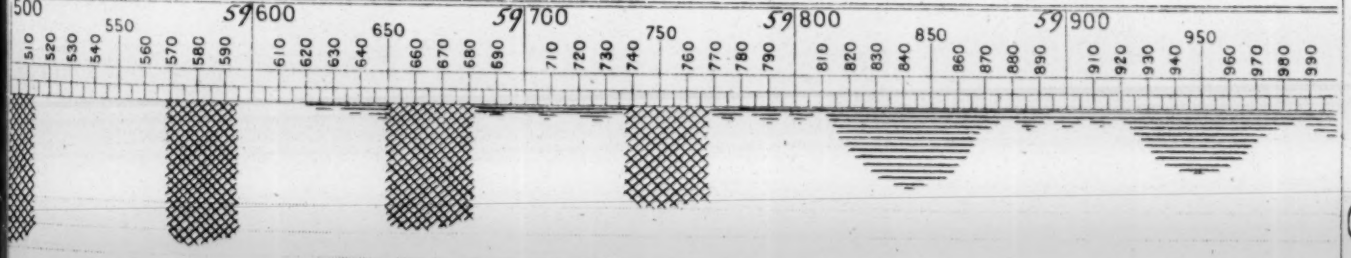
CH FLAME

= 37° A to H The definition is here more uncertain, and



CH FLAME

anywhere else; but there is so much of it as to form a



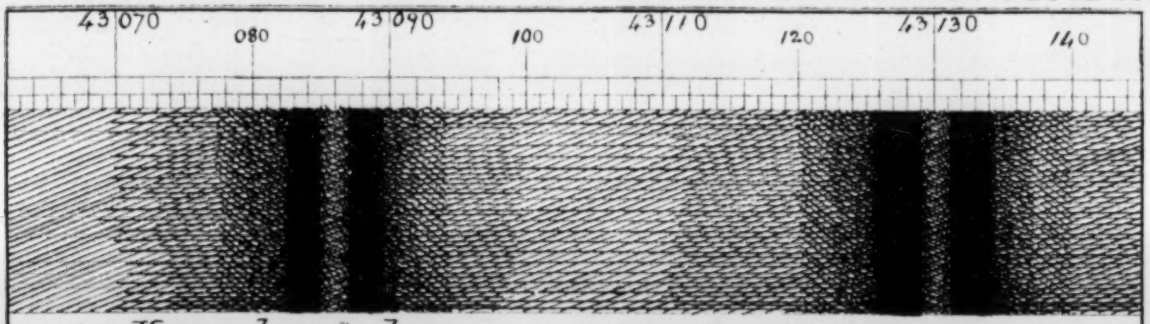
CH FLAME

CH FLAME

Photo-lith. 1884.

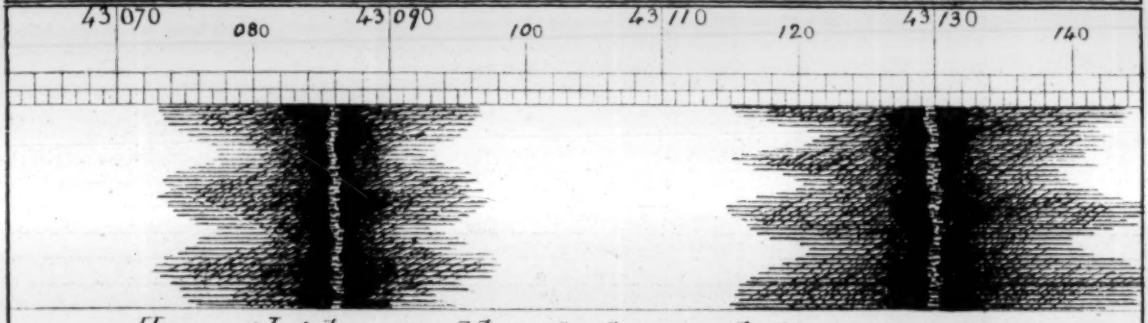
T H del. 2

D^1 AND D^2 OF SODIUM. OR Na. VAPOUR
AS THEY APPEAR IN DIFFERENT SUCCESSIVE METHODS OF INCANDESCENSE.



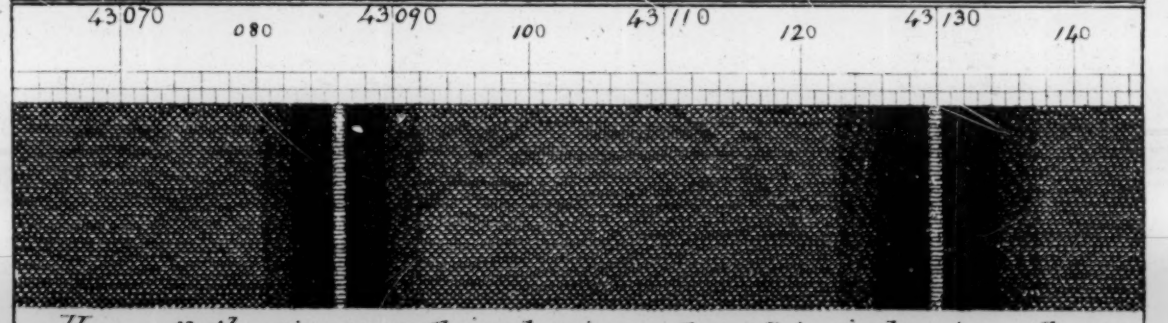
Here broad haziness preponderates

IN BUNSEN-BURNER GAS FLAME.



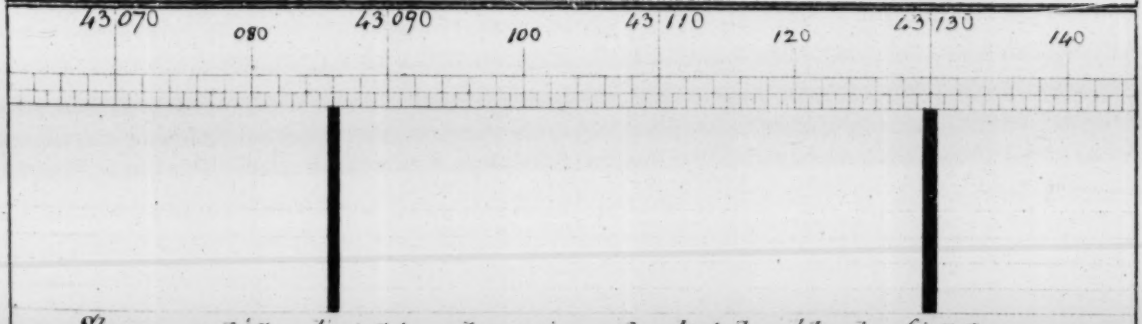
Here sketchy crackly sparks, exploding variously.

BY SIMPLE INDUCTION SPARK.



Here all the air around is glowing and quaking in luminous heat.

BY JAR DISCHARGE OR CONDENSED SPARK.

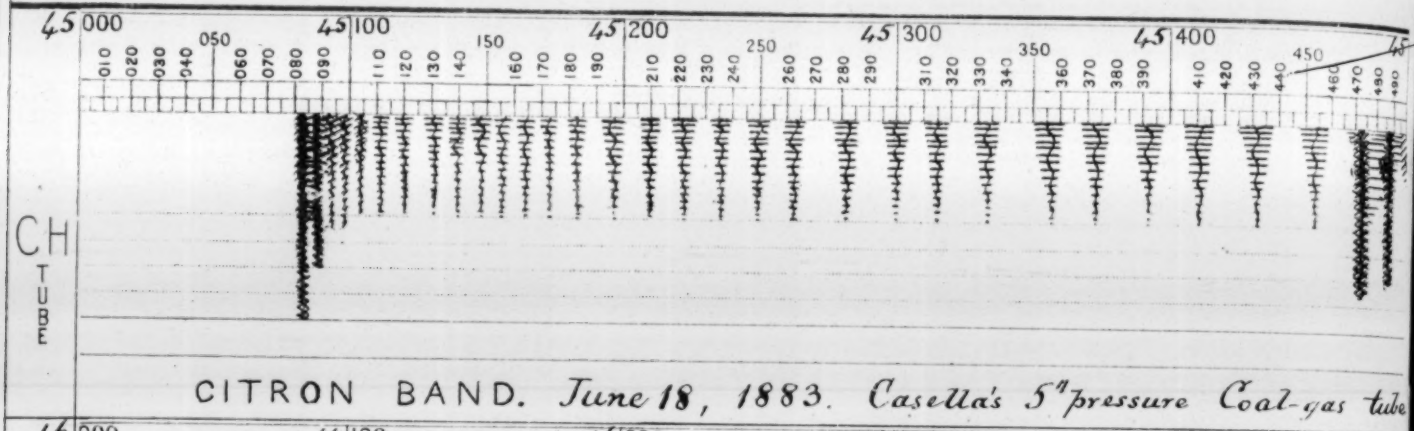


Sharp, solid, bright, clear in absolutely black field.

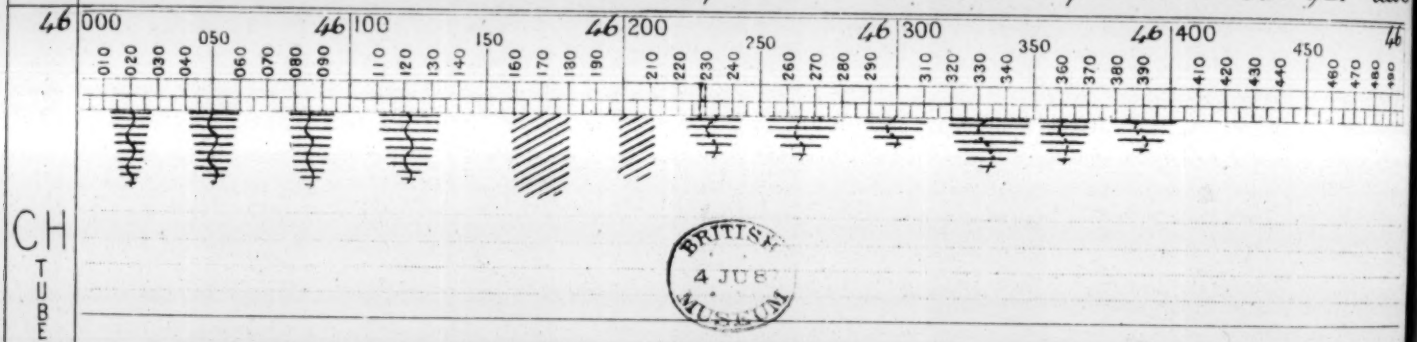
IN VACUUM TUBE.

C.H.Griffith del. 1 T.H. del. 2

CH IN VA

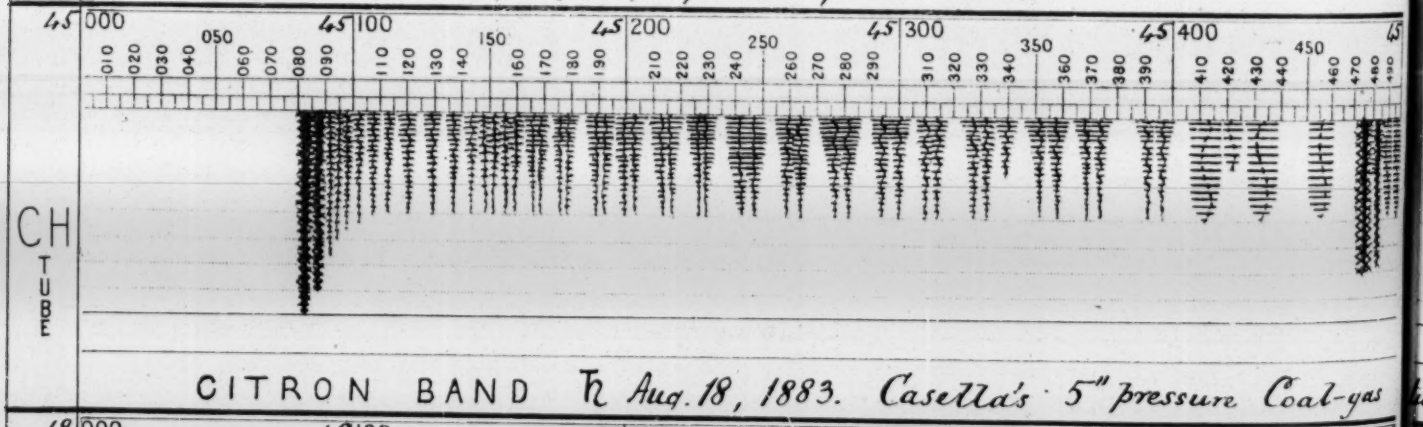


CITRON BAND. *June 18, 1883. Casella's 5" pressure Coal-gas tube*

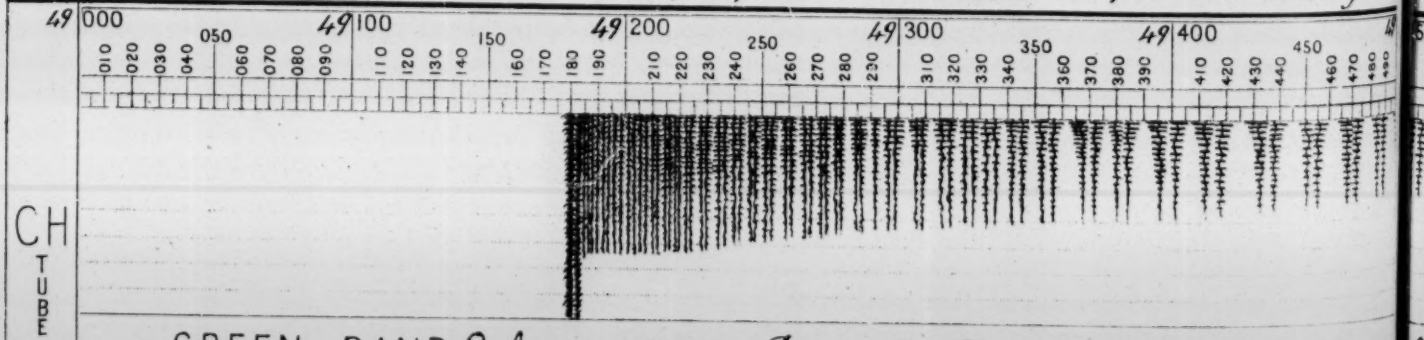


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CITRON BAND. (Cont^d.) *primary in Coil.*

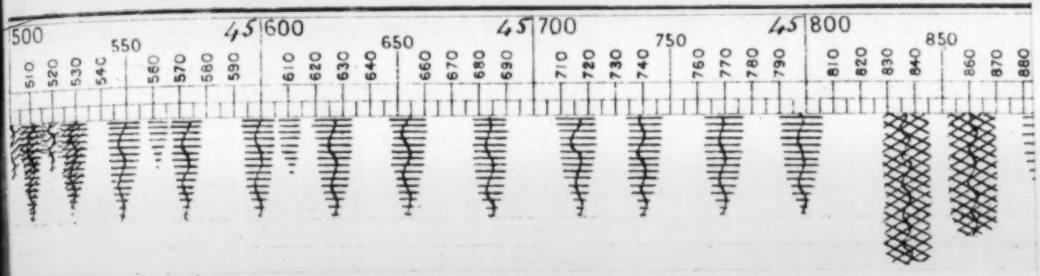


CITRON BAND ♄ *Aug. 18, 1883. Casella's 5" pressure Coal-gas*

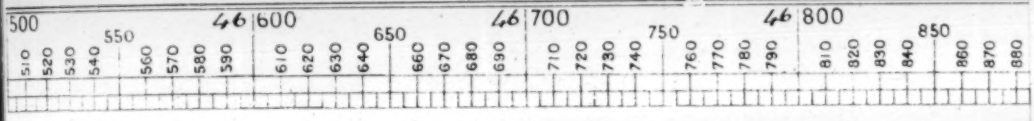


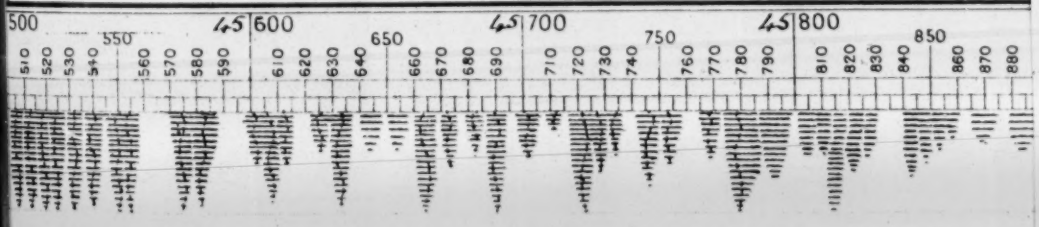
GREEN BAND ♀ *Aug 10. 1883. Casella's Coal-gas tube at 1" pressure*

CUUM - TUBE

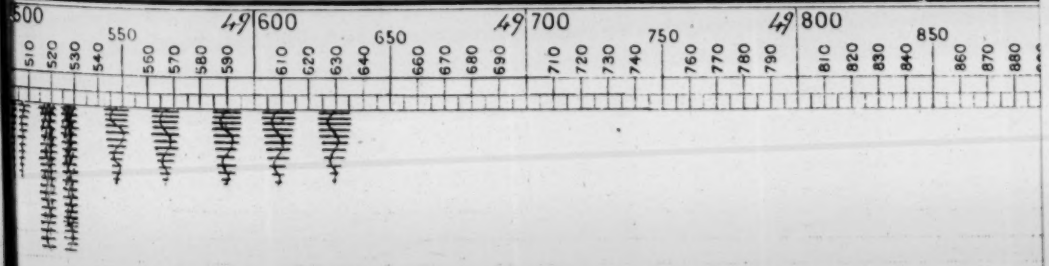


Prismatic Dispersion = ~~48~~ A to H Magnifying power





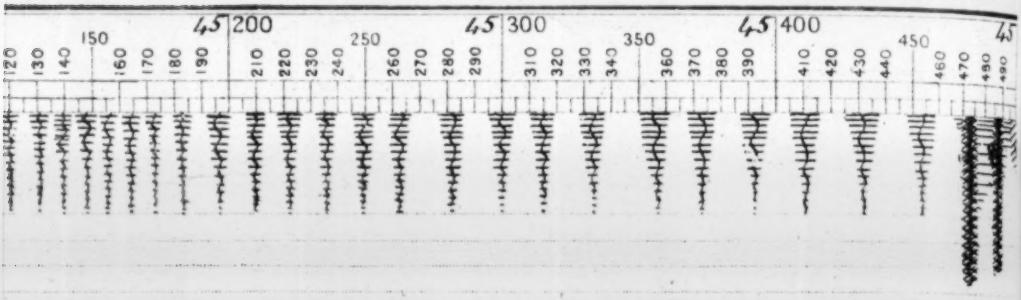
ube Prismatic Dispersion = 60° A to H. Mag. power = 12 and 2



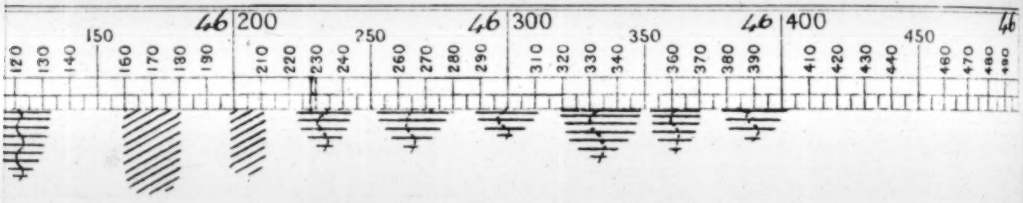
Viewed in Prof Rowlands Grating. 5th order.. Quantity Prim

Photo-lith. 1884.

CH IN VA

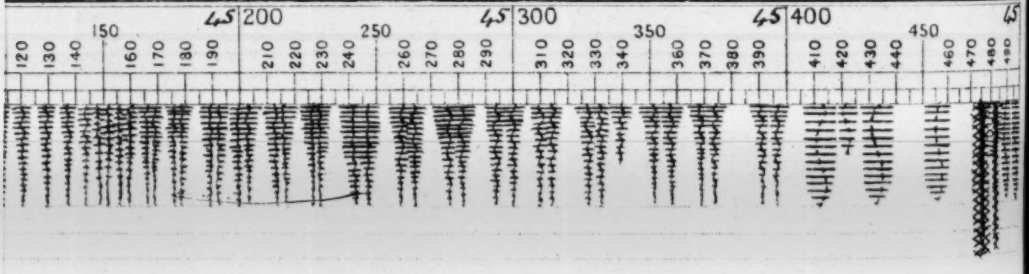


BAND. *June 18, 1883. Casella's 5" pressure Coal-gas tube*

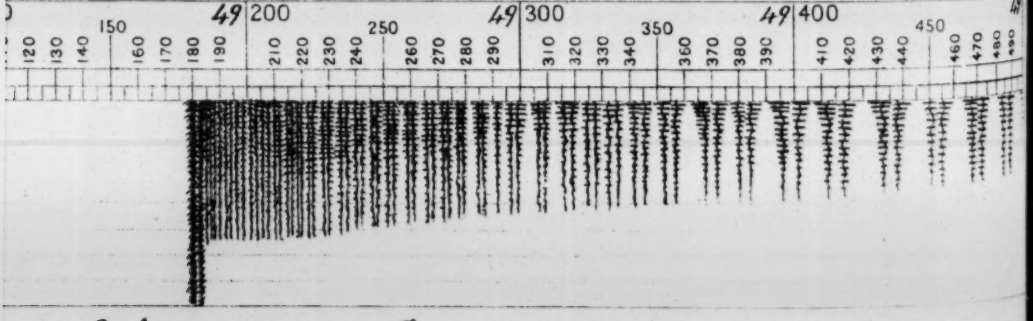


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BAND. (Cont^{d}) *primary in Coil.*



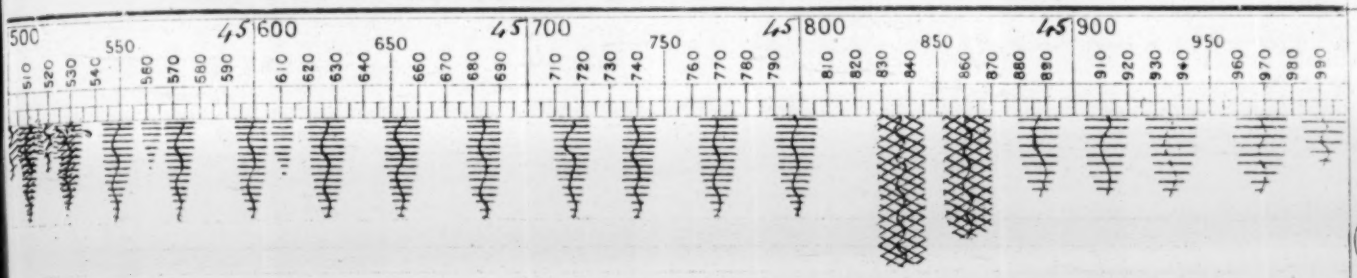
BAND *Th Aug. 18, 1883. Casella's 5" pressure Coal-gas tube*



AND. *♀ Aug 10. 1883. Casella's Coal-gas tube at 1" pressure*

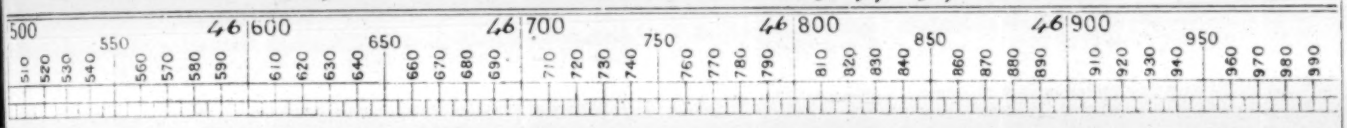
A. Ritchie & Son.

CUUM - TUBE

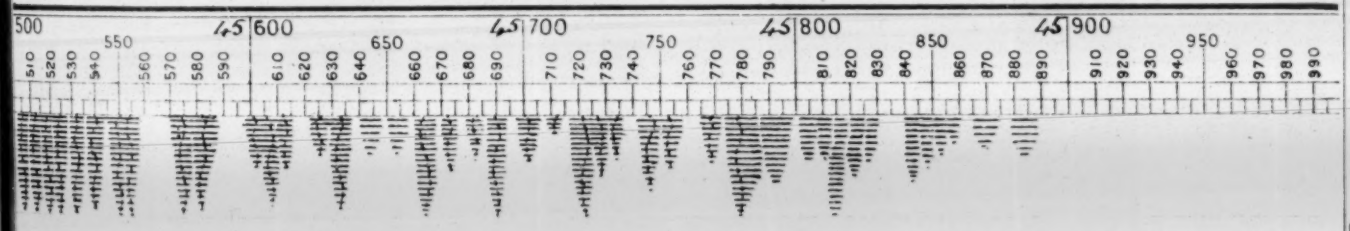


CH TUBE

Prismatic Dispersion = 48° A to H Magnifying power = 12. Quantity

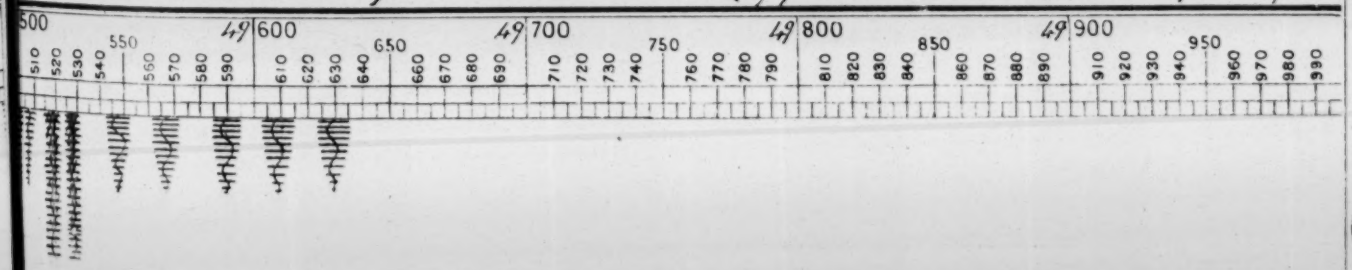


CH TUBE



CH TUBE

ube Prismatic Dispersion = 60° A to H. Mag. power = 12 and 21. Intensity Primary in Col.



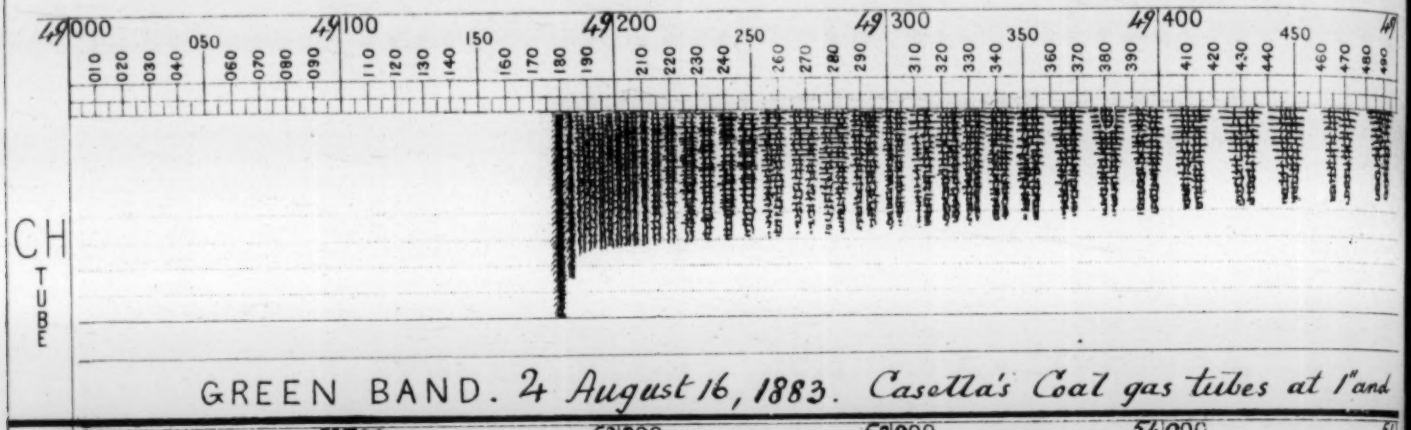
CH TUBE

Viewed in Prof Rowlands Grating. 5th order.. Quantity Primary. Abb's Coil.

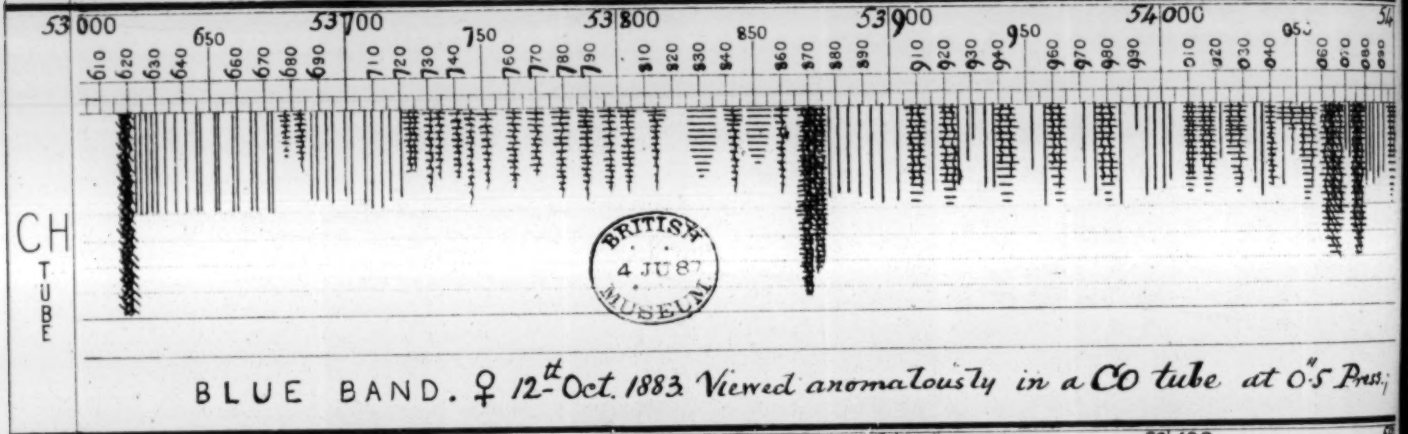
Photo-lith. 1884

T H del 2

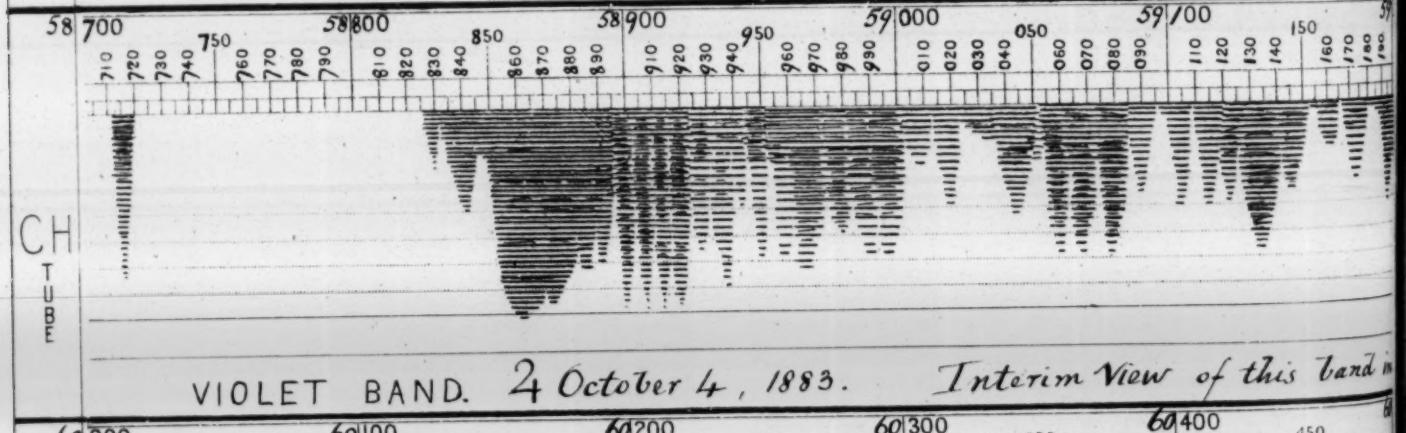
CH IN VA



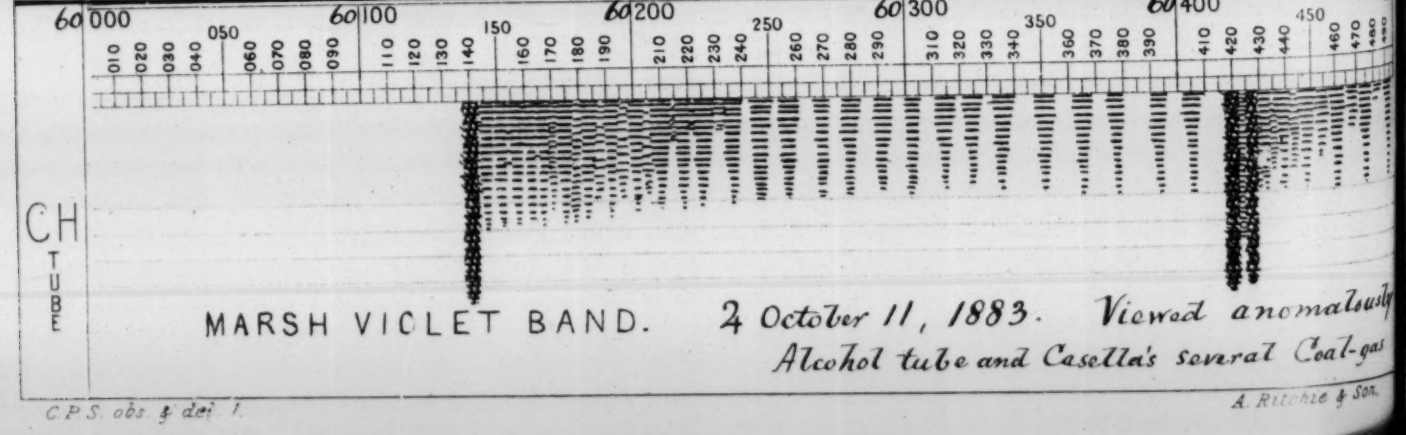
GREEN BAND. 2 August 16, 1883. Casella's Coal gas tubes at 1" and



BLUE BAND. ♀ 12th Oct. 1883. Viewed anomalously in a CO tube at 0".5 Pres.;



VIOLET BAND. 2 October 4, 1883. Interim View of this band in



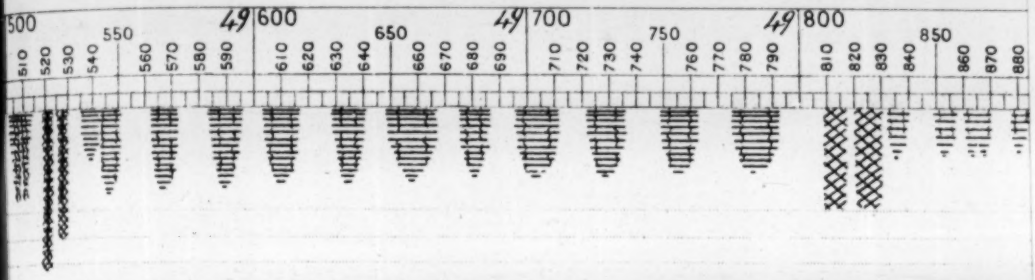
MARSH VIOLET BAND. 2 October 11, 1883. Viewed anomalously

Alcohol tube and Casella's several Coal-gas

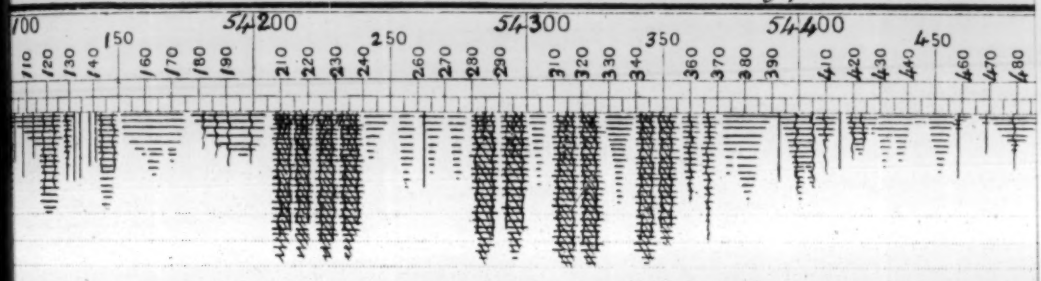
C.P.S. obs. & del. 1.

A. Ritchie & Son.

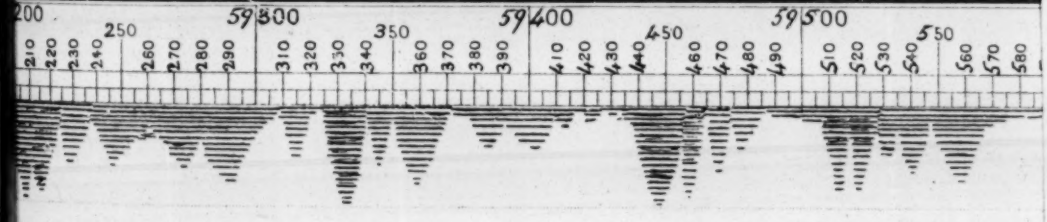
CUUM - TUBE



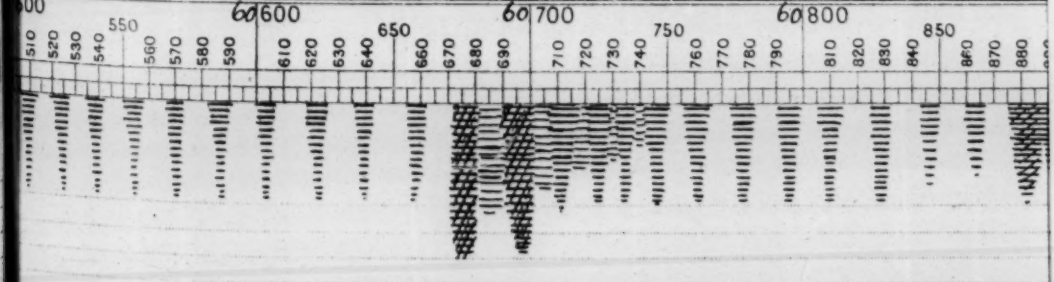
5" Pressure. Prismatic Dispersion = 60° A to H. Mag.l power = 12. Intensit



but with reference to Alcohol and Coal-gas tubes. Prism.tic Dispersion = 48° A to H



perishing Alcohol, Coal-gas and Olefiant tubes Prism. Disp. = 36° A to H

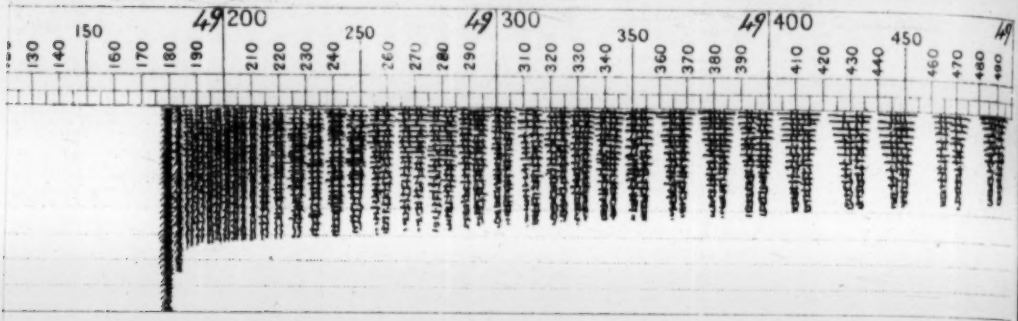


as an impurity in Sharp's 0·5 Press.re H tube, and compared w

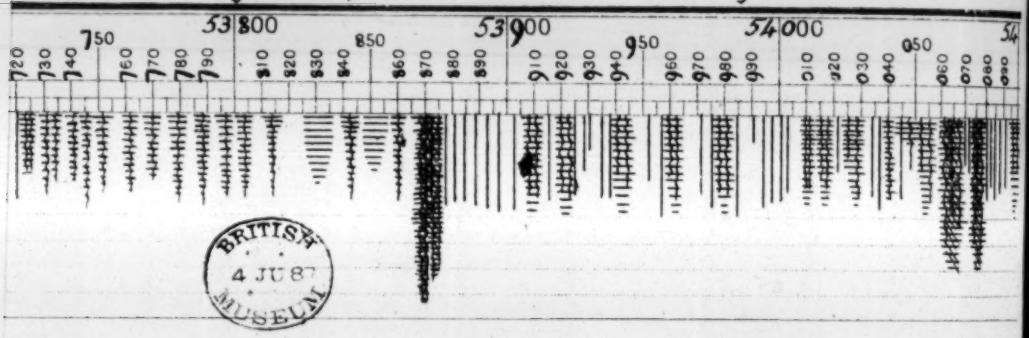
ubes. Prismatic Dispersion = 36° A to H ; Mag. power = 21.

Photo-lith. 1884.

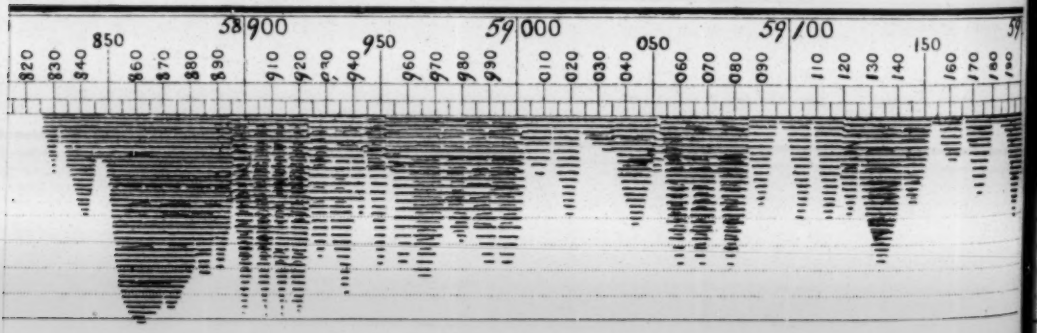
CH IN VA



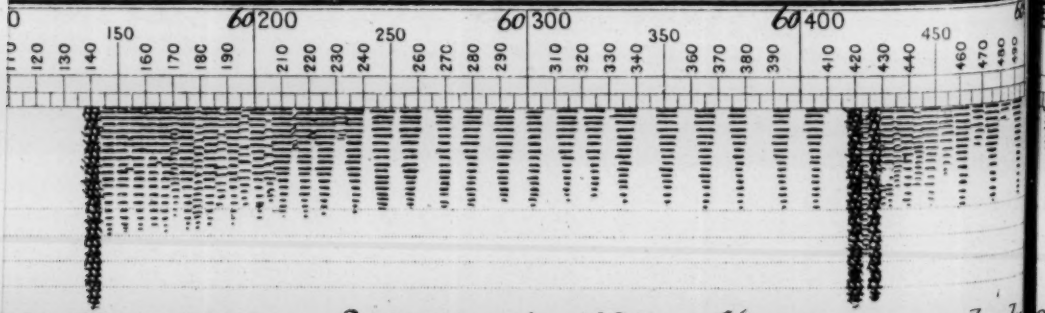
AND. 4 August 16, 1883. Casella's Coal gas tubes at 1" and



ND. ♀ 12th Oct. 1883 Viewed anomalously in a CO tube at 0".5 Pressure



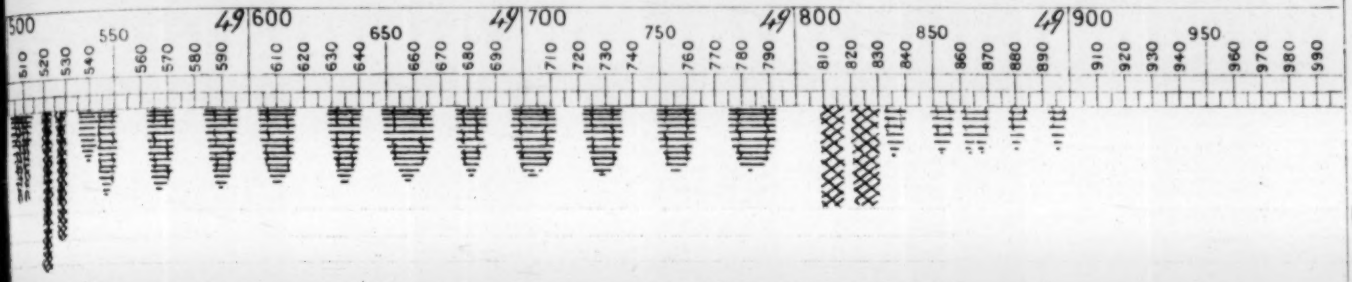
AND. 4 October 4, 1883. Interim View of this band in



IOLET BAND. 4 October 11, 1883. Viewed anomalously as an
Alcohol tube and Casella's several Coal-gas tubes.

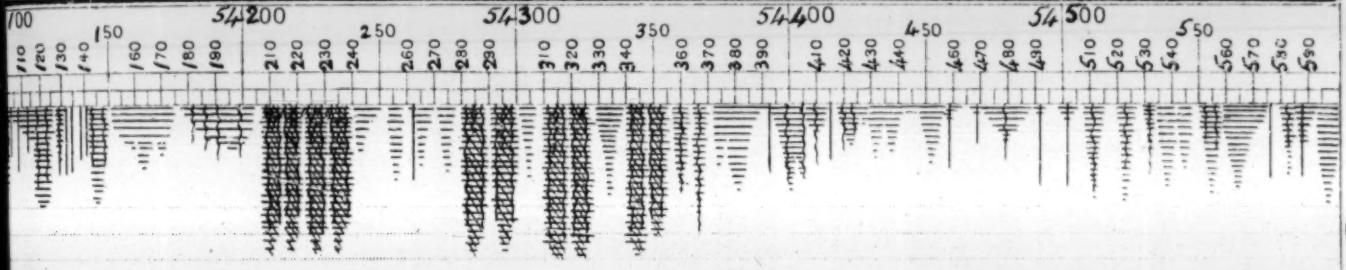
A. Ritchie & Son.

CUUM - TUBE



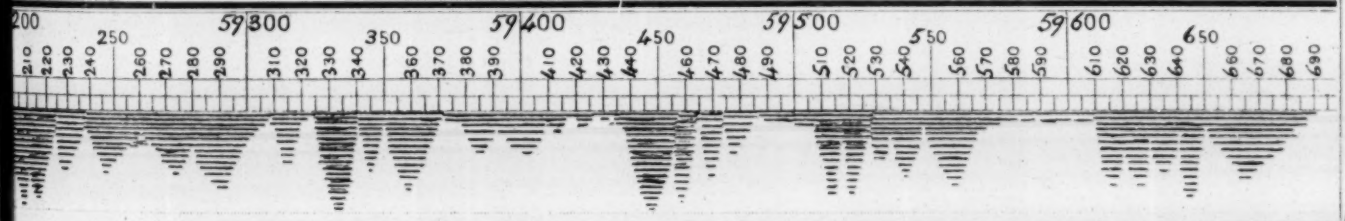
CH TUBE

5" Pressure. Prismatic Dispersion = 60° A to H. Mag.l power = 12. Intensity Primary in App's Coil.



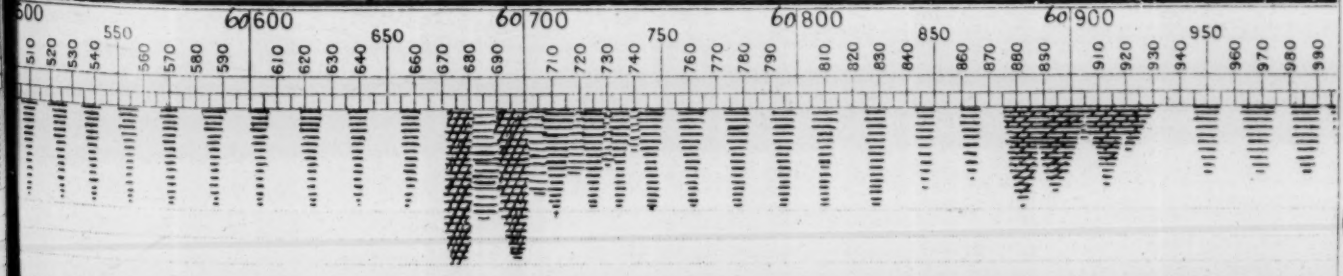
CH TUBE

but with reference to Alcohol and Coal-gas tubes. Prism.tic Dispersion = 48° A to H, Mag. power = 21.



CH TUBE

perishing Alcohol, Coal-gas and Olefiant tubes Prism. Disp. = 36° A to H, Mag. power = 21.



CH TUBE

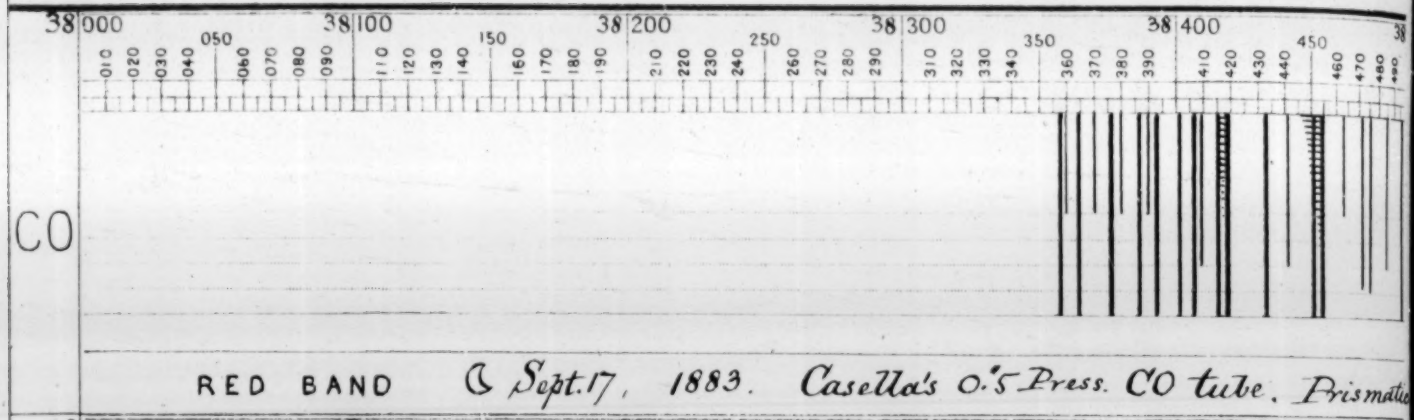
as an impurity in Sharp's 0·5 Press.re H tube, and compared with Salleron's

ubes. Prismatic Dispersion = 36° A to H; Mag. power = 21.

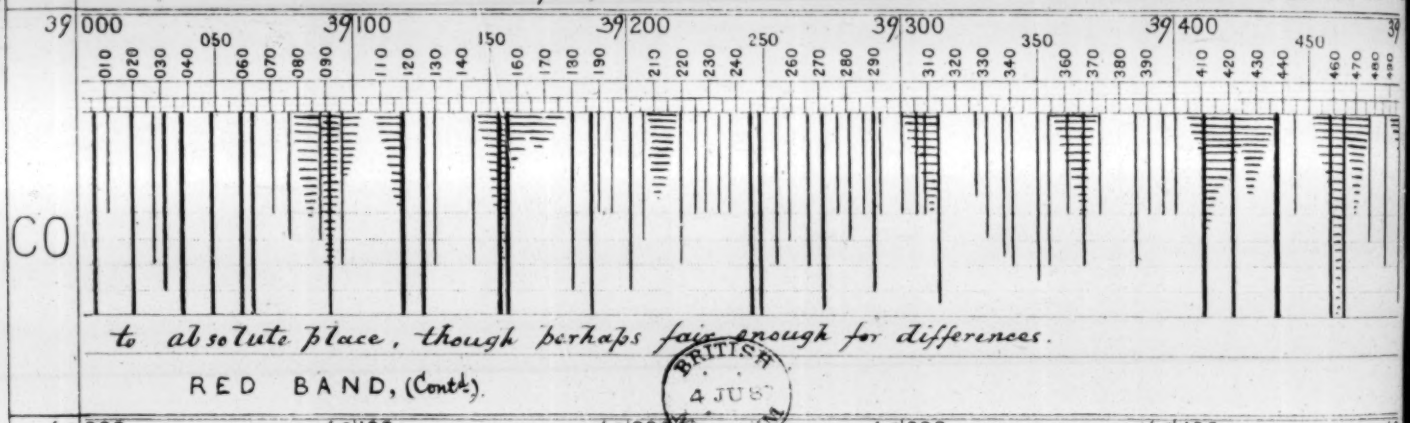
Photo-Lith 1884.

T.H del 2

CO IN VA-C



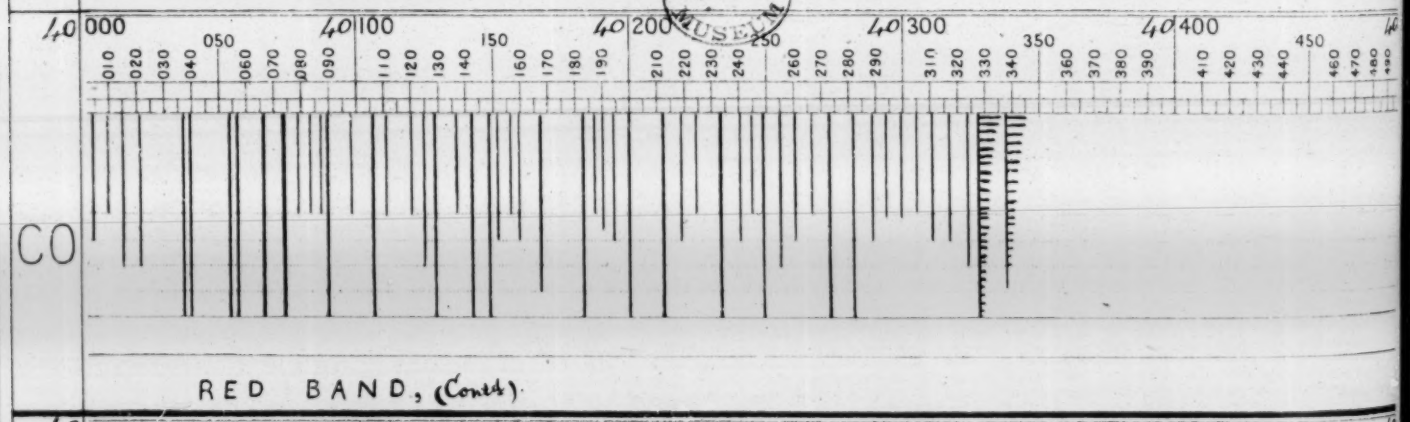
RED BAND @ Sept. 17, 1883. Casella's 0·5 Press. CO tube. Prismatic



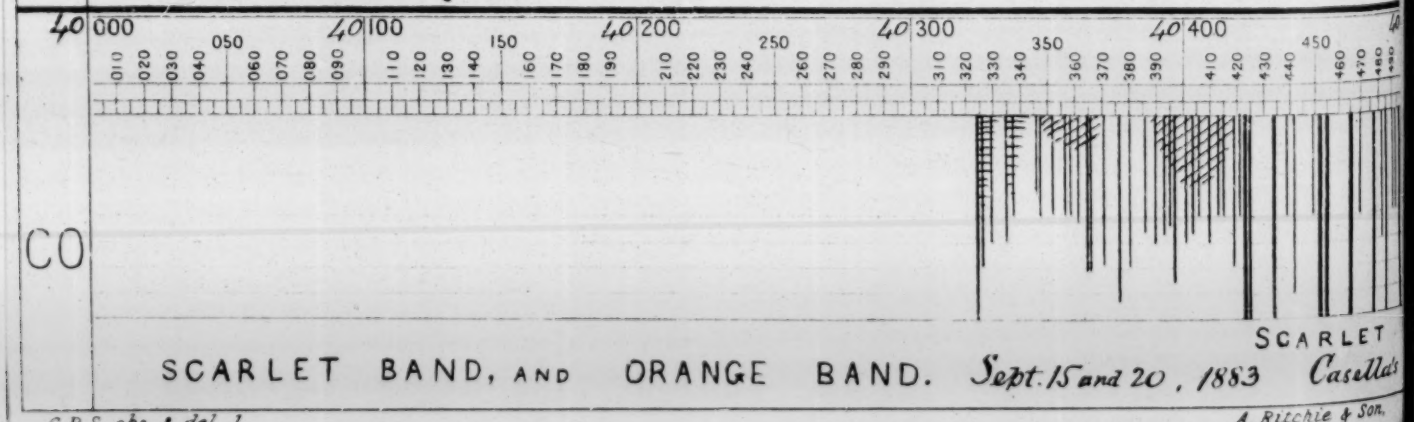
to absolute place, though perhaps fair enough for differences.

RED BAND, (Contd.)

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RED BAND, (Contd.)

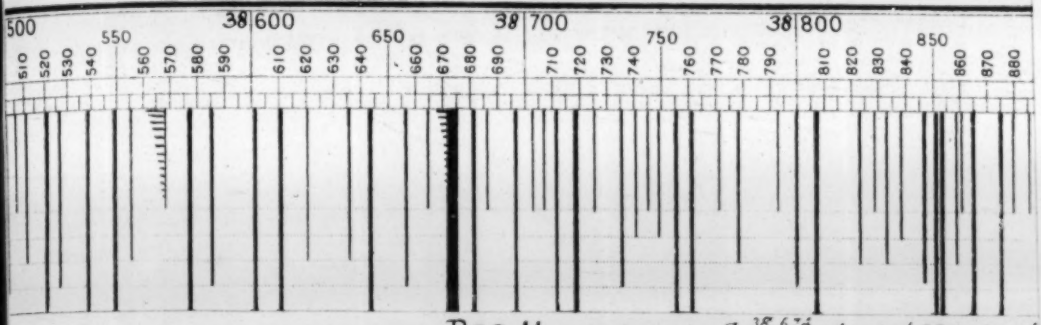


SCARLET BAND, AND ORANGE BAND. Sept. 15 and 20, 1883 Casella's

C.P.S. obs. & del. 1.

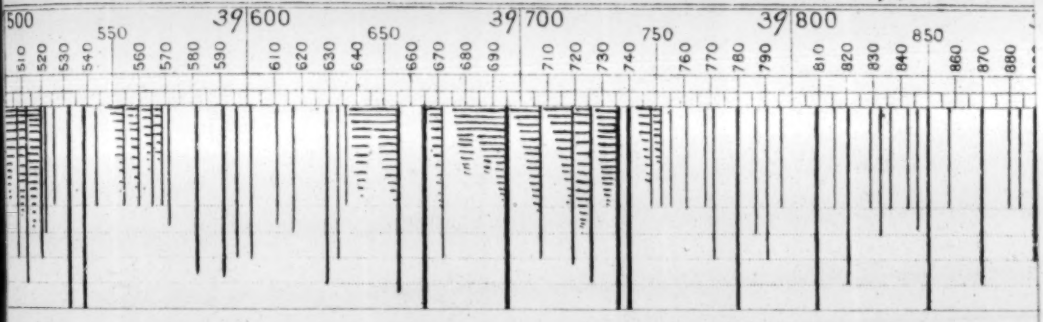
A. Ritchie & Son.

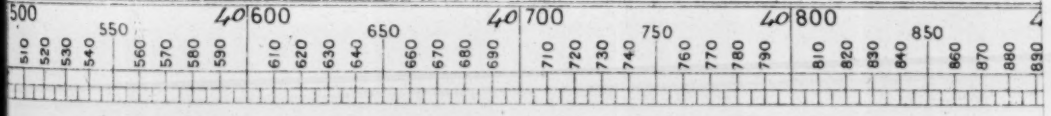
A-CUUM - TUBE

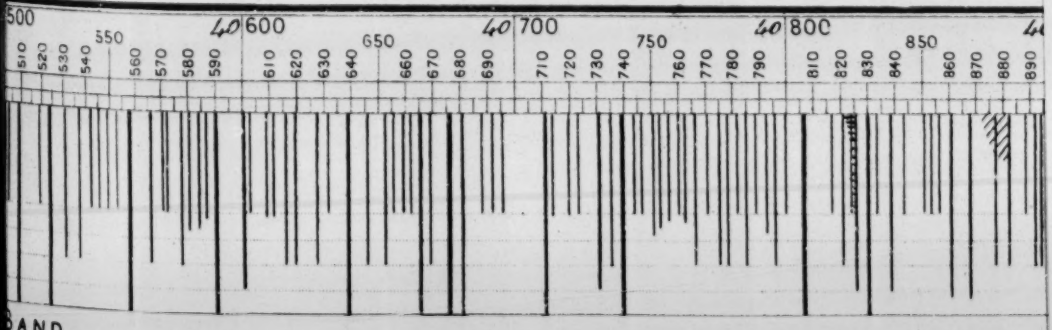


RED H coming in here 38.67½ and not at 38 707. sh

Dispersion = 60° A-to H. Quantity Primary in App Coil





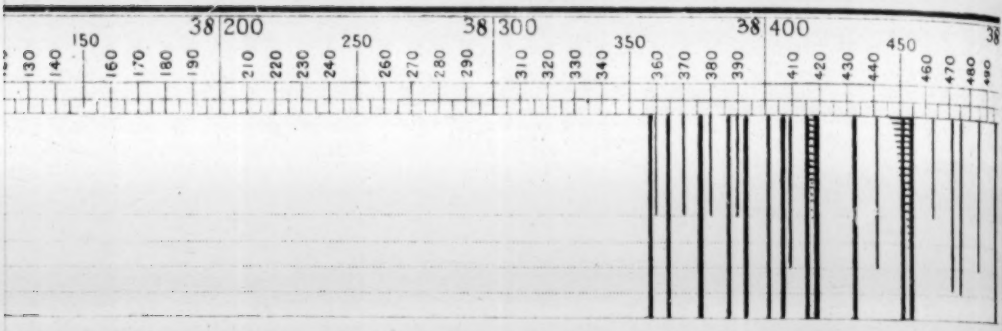


SAND.

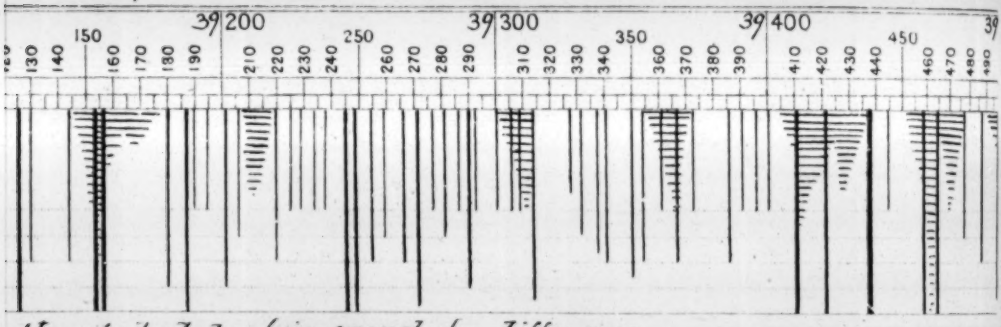
tubes of CO at 0·5 and 2·5 Pressure, also Demichel's CO tube

Photo-Lith. 1884.

CO IN VA-C



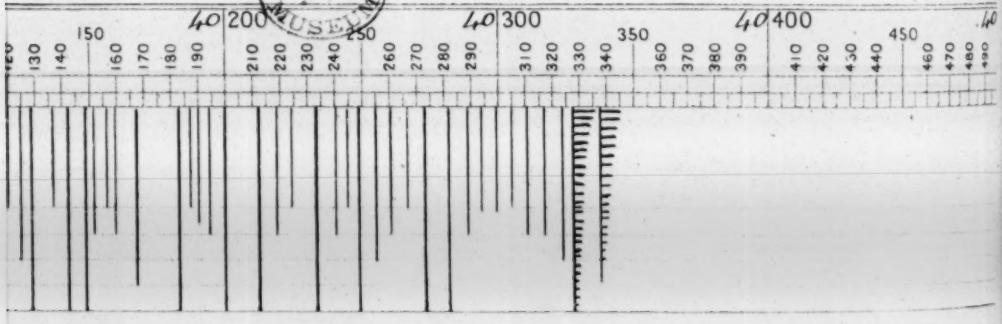
& Sept. 17, 1883. Casella's 0·5 Press. CO tube. Prismatic Du



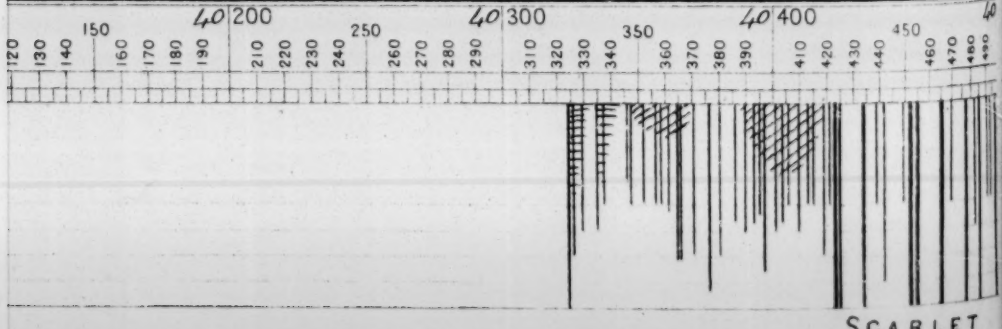
though perhaps fair enough for differences.

(Contd).

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, (Contd).

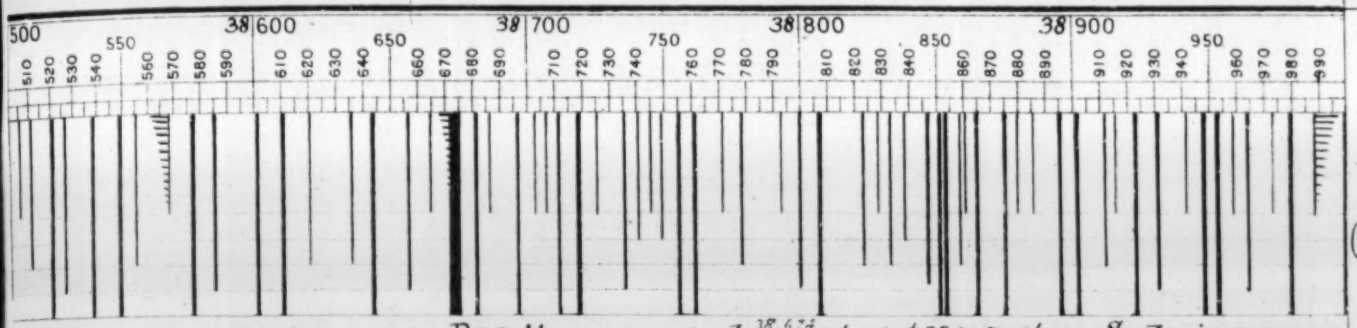


SCARLET

ND, AND ORANGE BAND. Sept. 15 and 20, 1883 Casella's BAND. tube

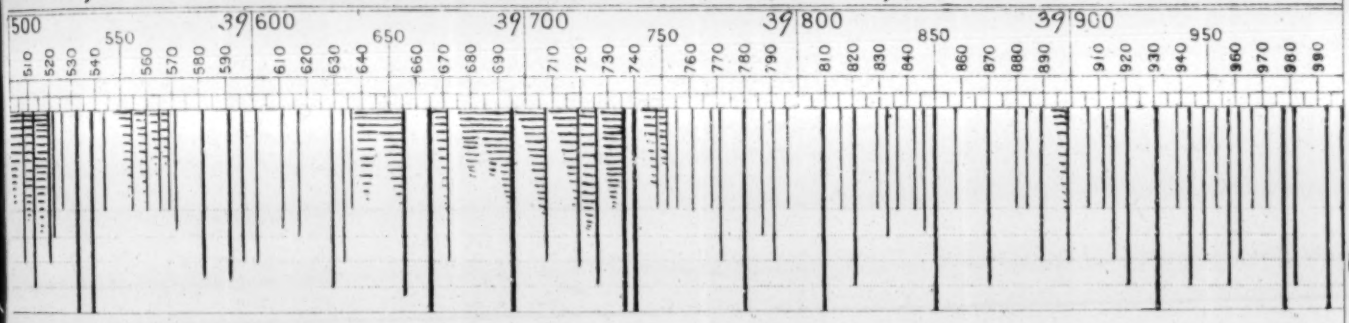
A. Ritchie & Son. Photo-L

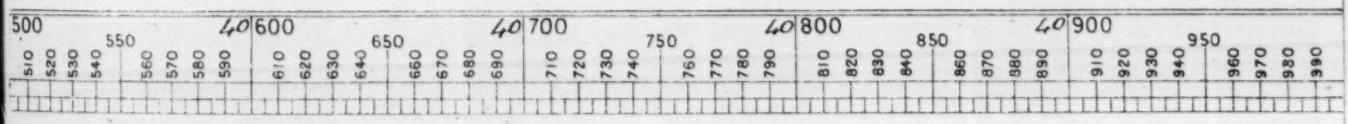
-CUUM - TUBE



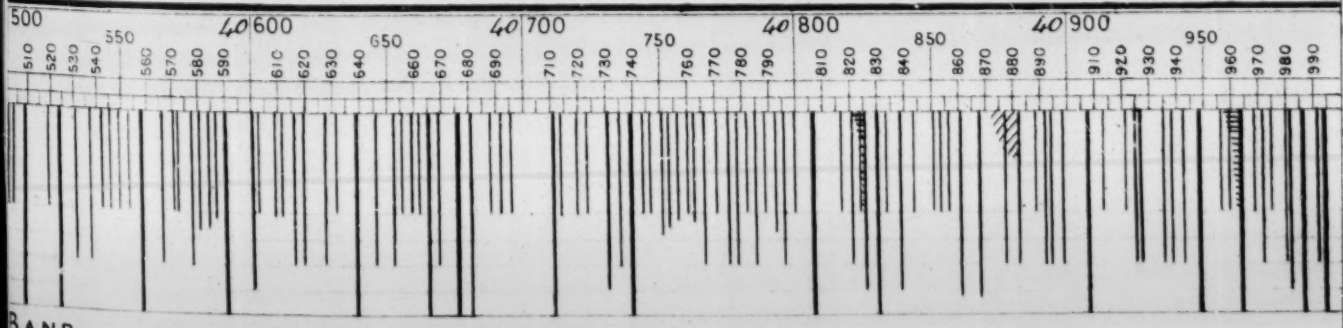
RED H coming in here, 38.674 and not at 38 707. shows Scale in error as

Dispersion = 60° A to H. Quantity Primary in App Coil.





CO

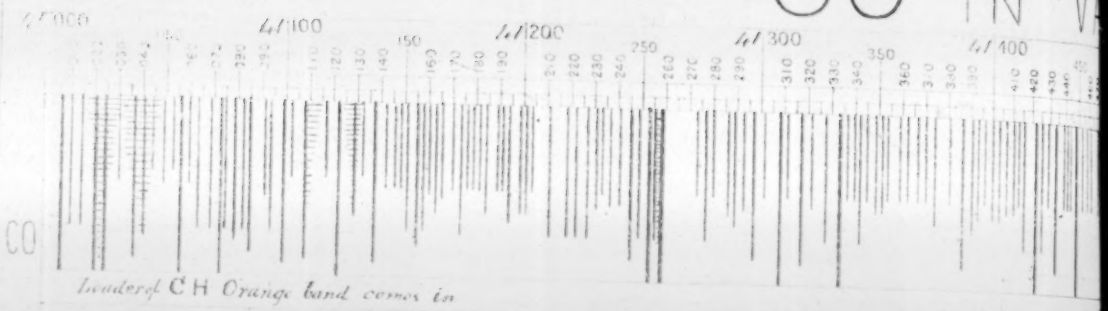


BAND.

tubes of CO at 0·5 and 2·5 Pressure, also Dernichel's CO tubes which are

Trans. Roy. Soc. Edin.

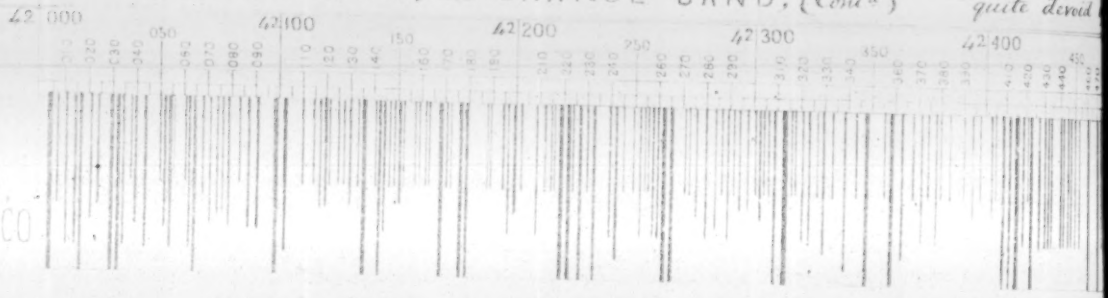
CO IN V



Leader of CH Orange band comes in

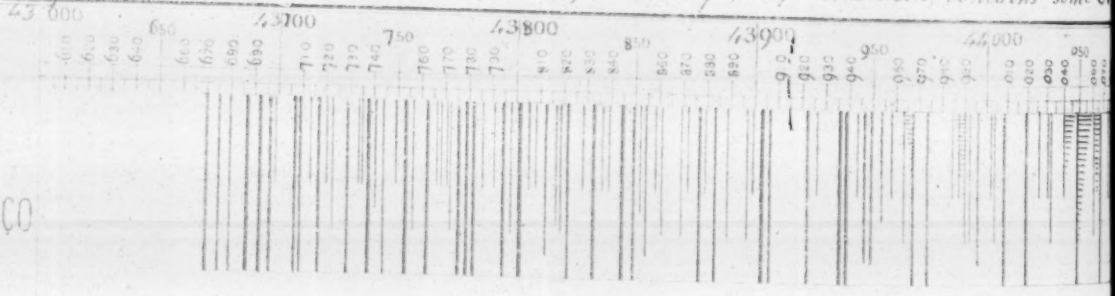
SCARLET BAND, AND ORANGE BAND, (Cont^d)

quite devoid



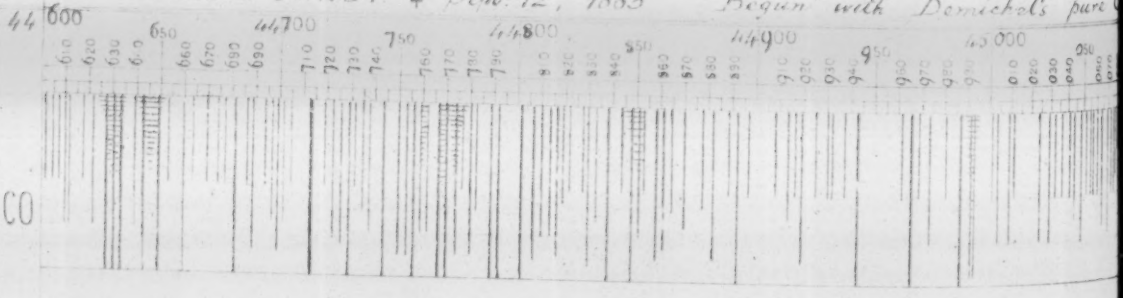
ORANGE BAND, ALONE, (Cont^d)

watery Sulphuric acid, contains some CH



YELLOW BAND. ♂ Sept. 12, 1883

Begun with Dumichel's pure

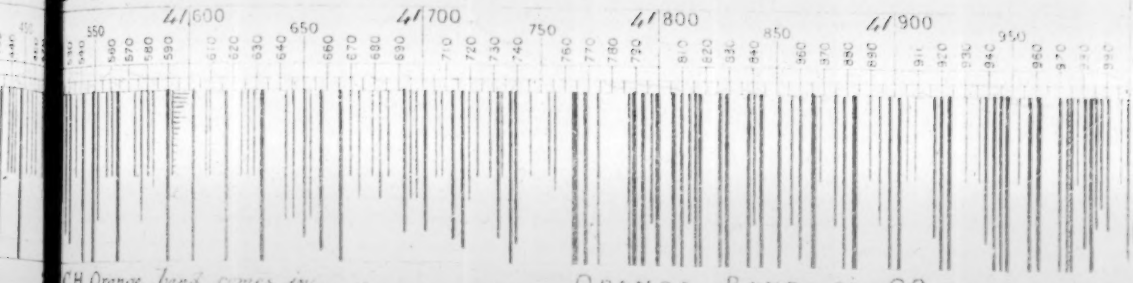


YELLOW BAND, (Cont^d) but impure with CH. Prismatic Dispersion = 60°

C.P.S. del. & sc.

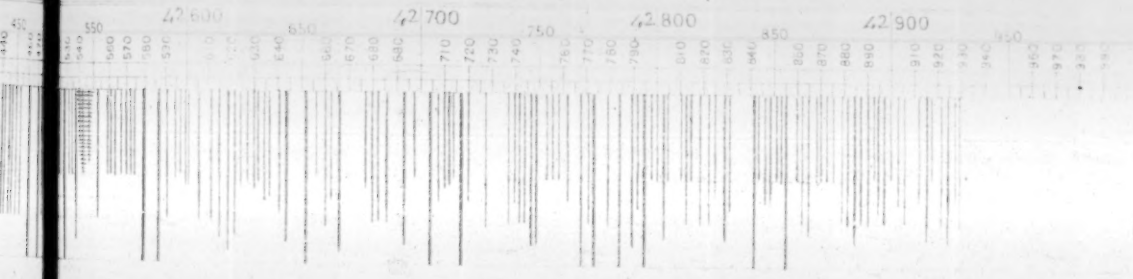
A. Ritchie & Sin

VACUUM - TUBE

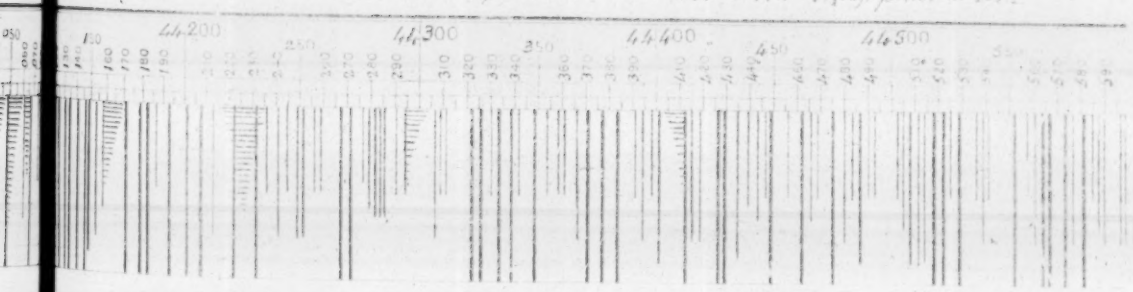


CH Orange band comes in. ORANGE BAND OF CO.

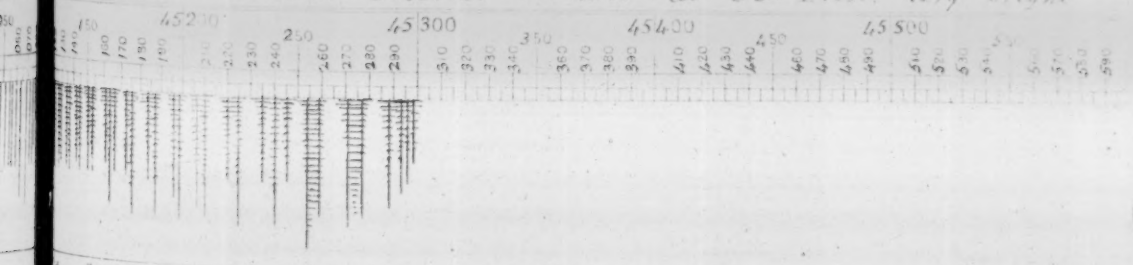
impurities either of H or CH. Casella's CO, prepared with weak



no H, impurities. Prismatic Dispersion = 60°. A to H. Mag^g power = 21.



and finished with Casella's CO tube at 0"5 Press. very bright

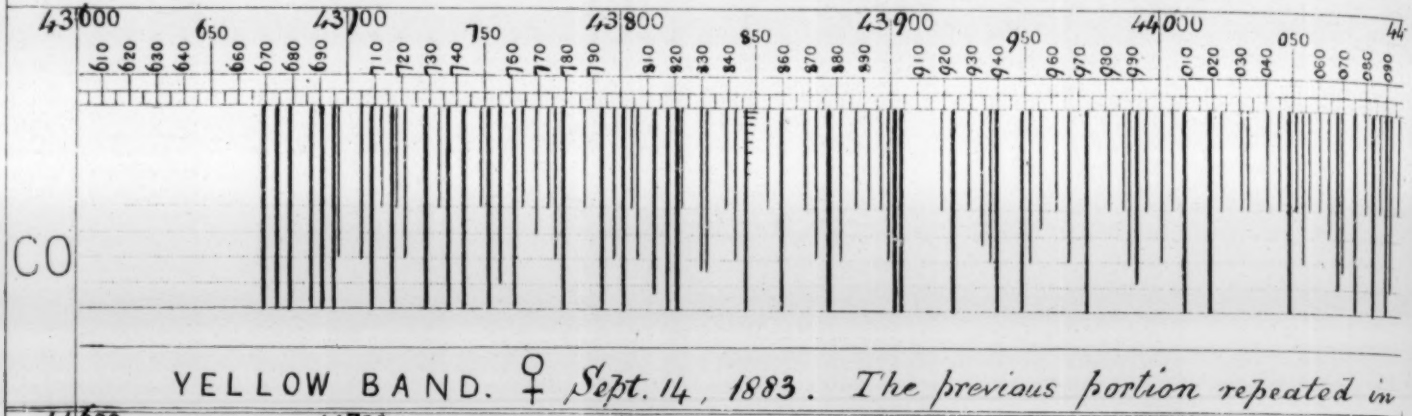


ron band impurity.

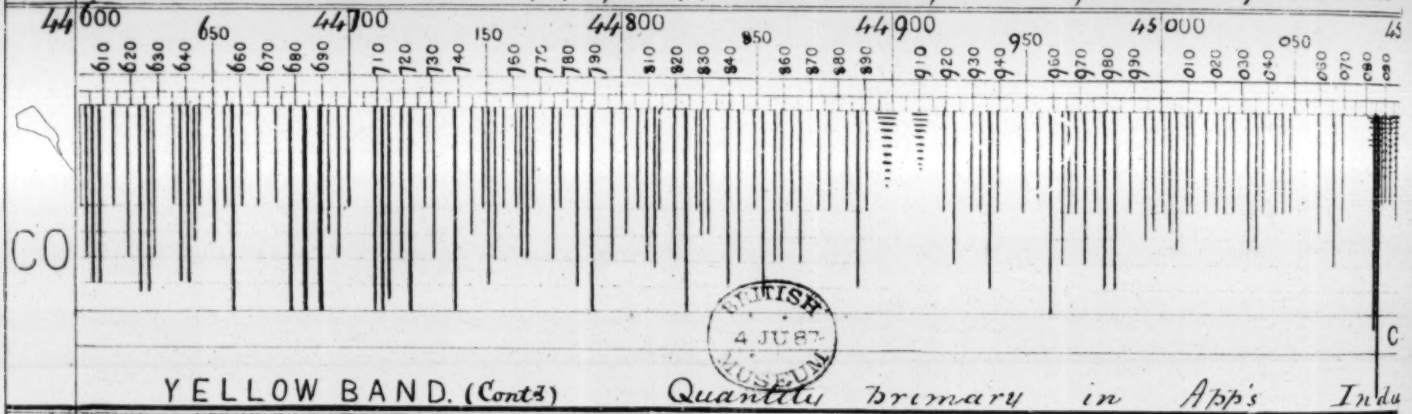
Illum^n = 21. Quantity Primary in App's Induction Coil

Feb. 15th. 1884

CO IN VA-

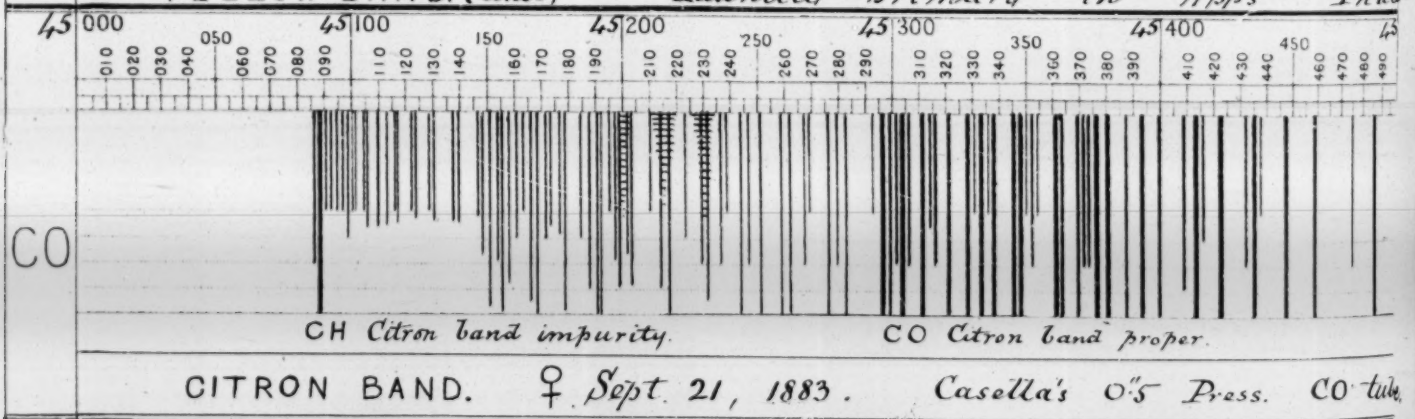


YELLOW BAND. ♀ Sept. 14, 1883. The previous portion repeated in



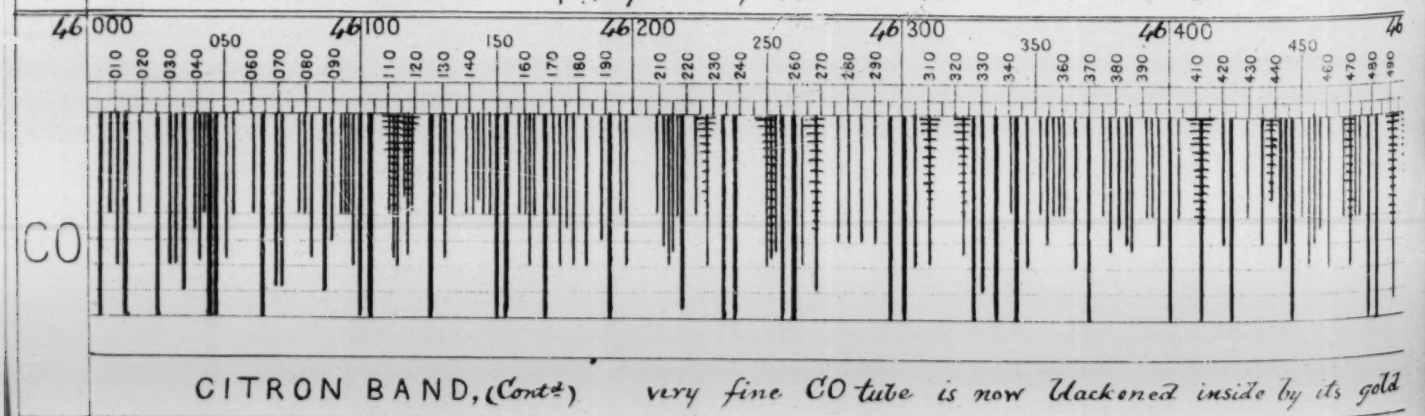
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YELLOW BAND. (Cont3) Quantity primary in App's Indu



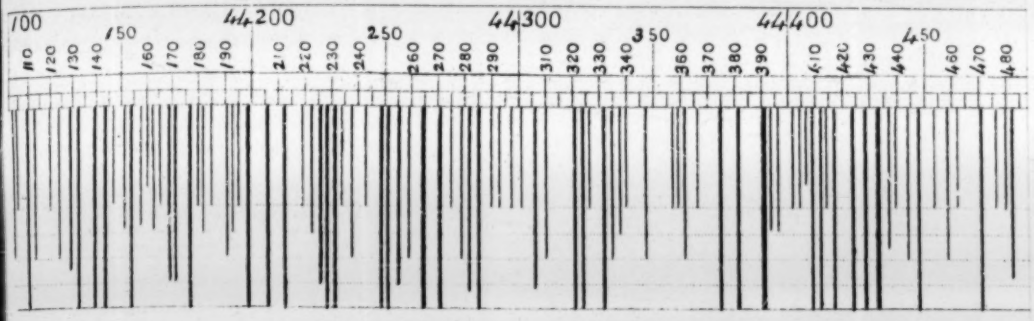
CH Citron band impurity. CO Citron band proper.

CITRON BAND. ♀ Sept. 21, 1883. Casella's 0"5 Press. CO tube

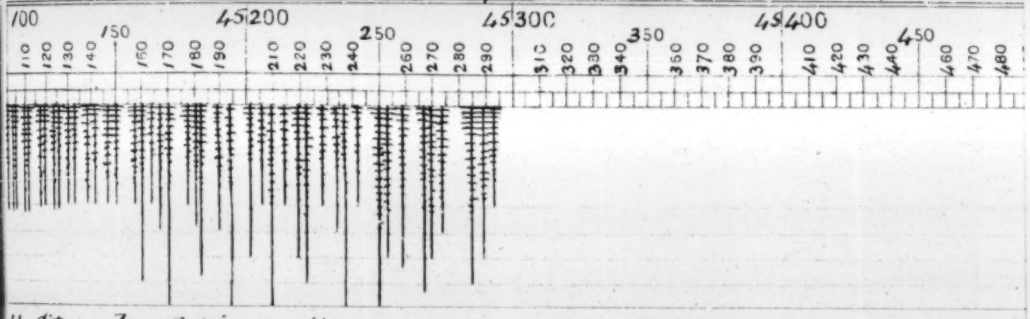


CITRON BAND, (Cont4) very fine CO tube is now blackened inside by its gold

CUUM - TUBE

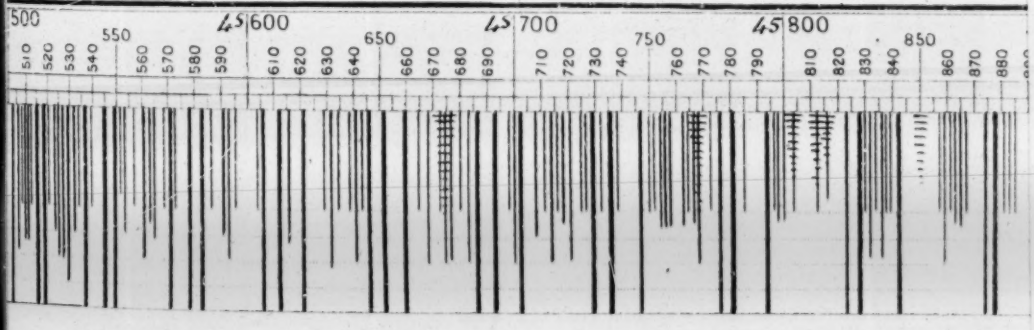


every particular, except with Intensity, in

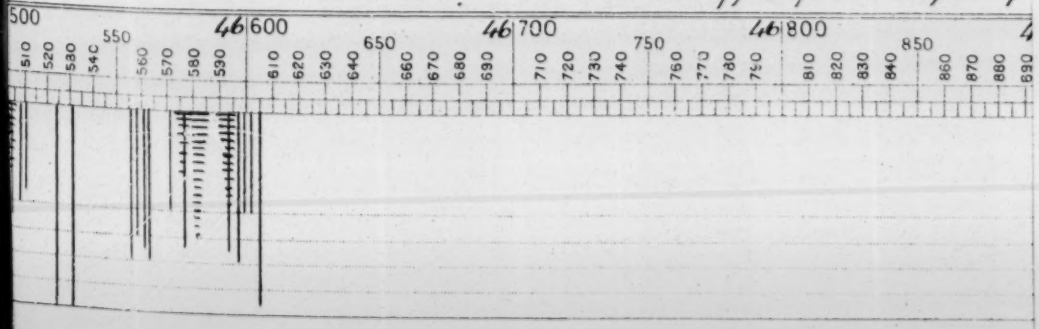


H Citron band impurity.

ction. Coil.



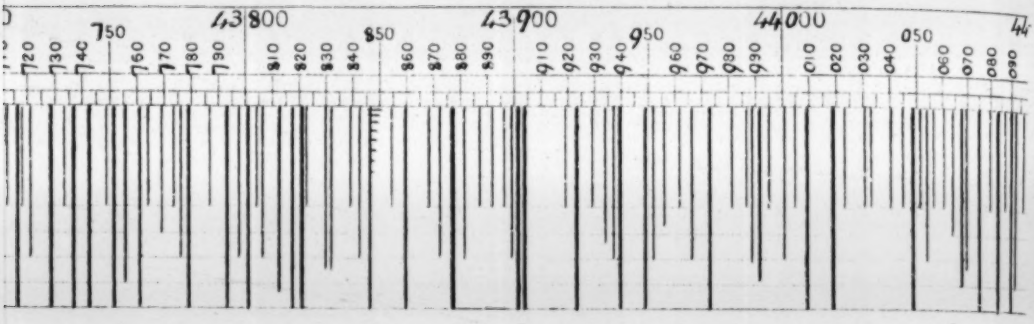
and his $CO + CO^2$ tube at Press. 0.2 and nearly free of CH impurity



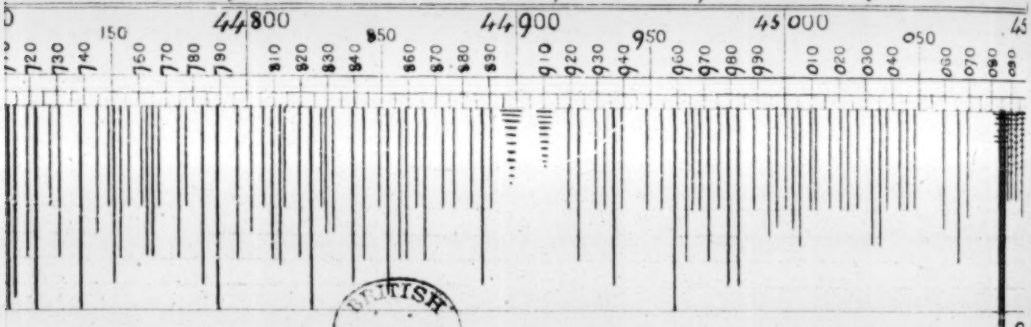
lectrodes. Prismatic Dispersion = 60° A to H. Mag. power

Photo-lith. 1884

CO IN VA-

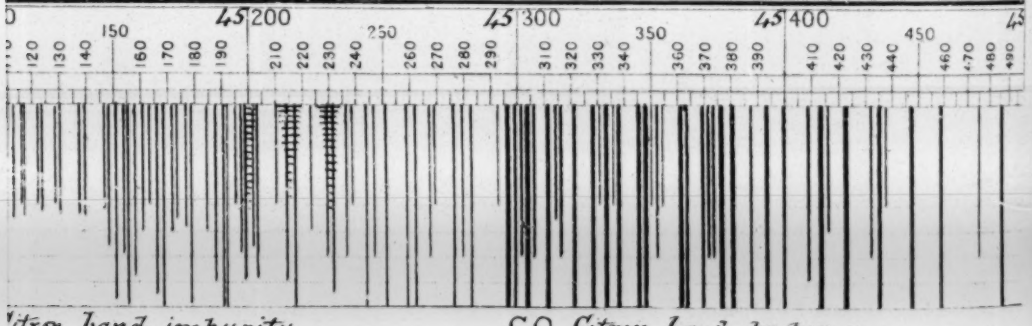


AND. ♀ *Sept. 14, 1883. The previous portion repeated in*



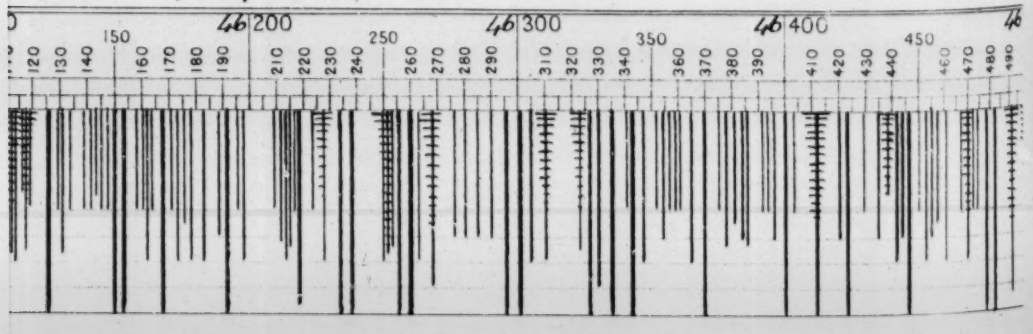
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ND. (Cont^{d}) *Quantity primary in App's Indu*



itron band impurity. *CO Citron band proper.*

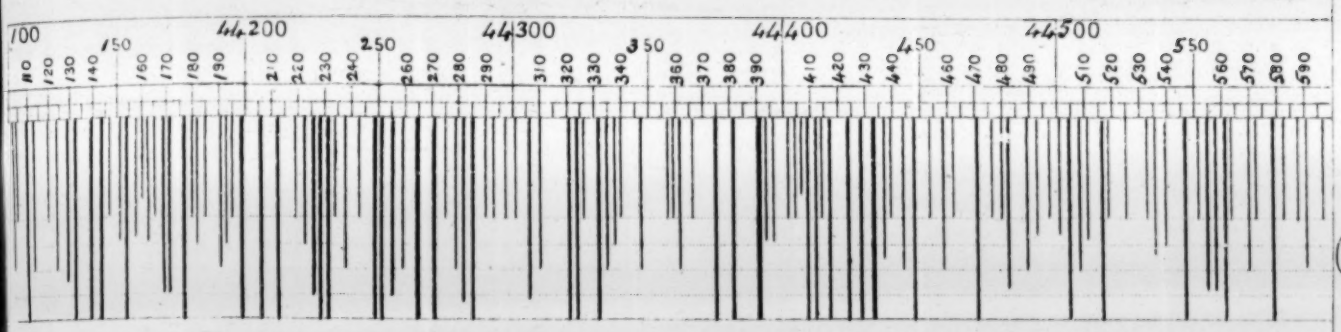
AND. ♀ *Sept. 21, 1883. Casella's 0.5 Press. CO tube*



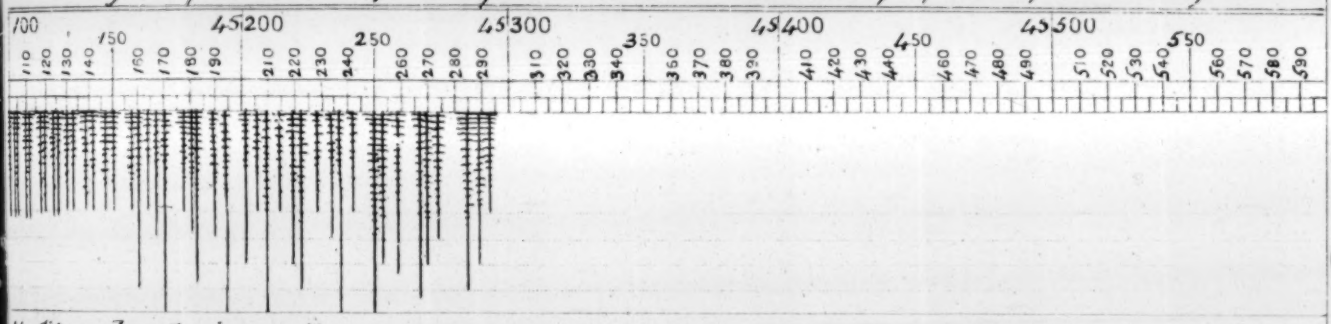
AND, (Cont^{d}) *very fine CO tube is now blackened inside by its gold*

A. Ritchie & Son.

·CUUM - TUBE

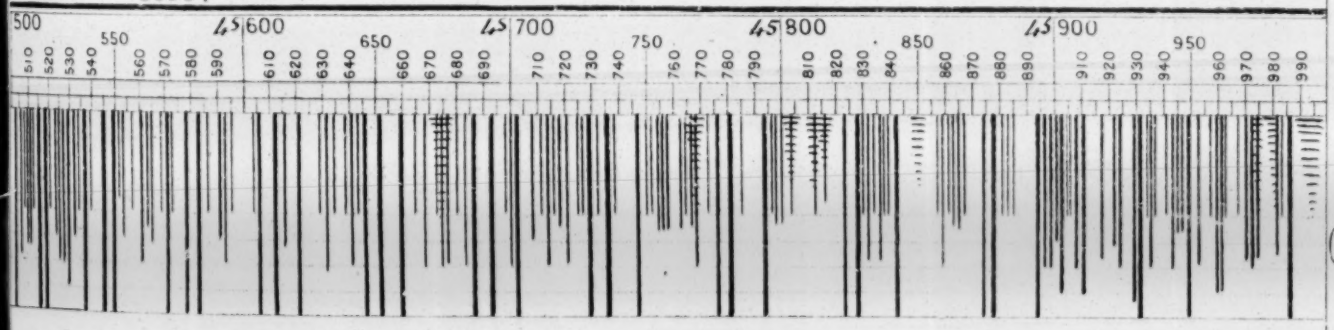


every particular, except with Intensity, in place of

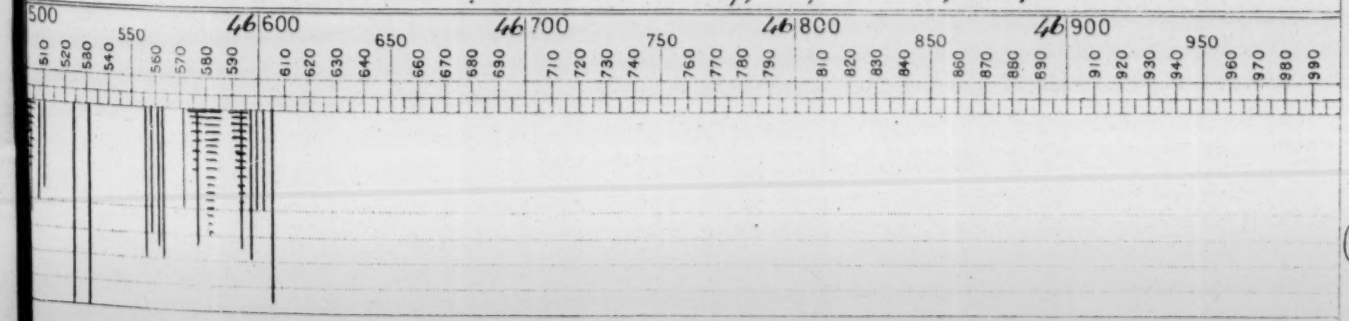


H Citron band impurity.

ction. Coil.



and his $CO + CO^2$ tube at Press. 0"2 and nearly free of CH impurity Dernickel's

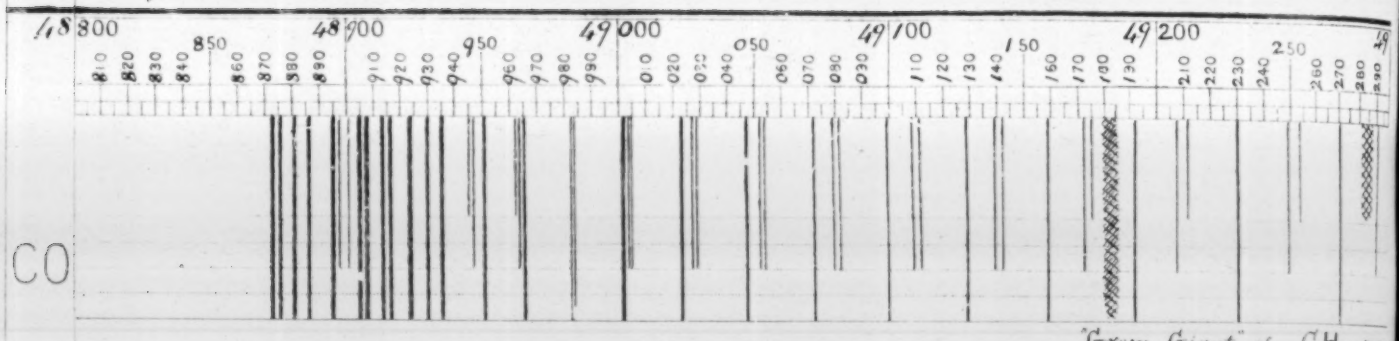


lectrodes. Prismatic Dispersion = 60° A to H. Mag. power = 21.

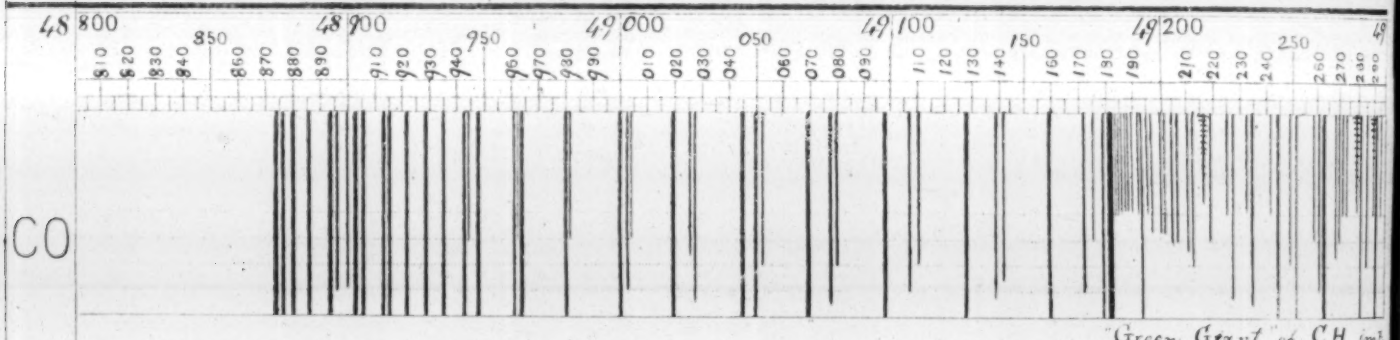
hoto-lith. 1884

T.H. del.

CO IN VA-



GREEN BAND. ♀ Aug. 10, 1883. Casella's CO tube at 0".1 Pressure.

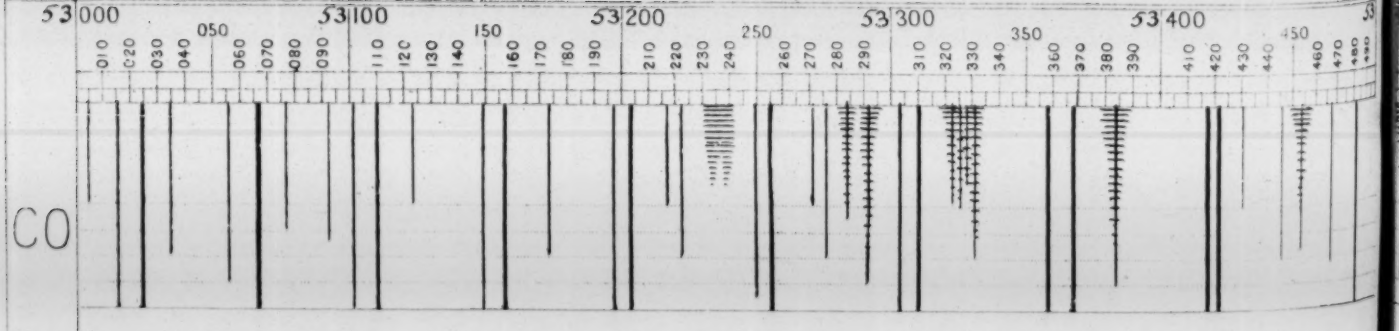


GREEN BAND. ☾ Sept. 24, 1883. Green CO intruded into by Green CH, in



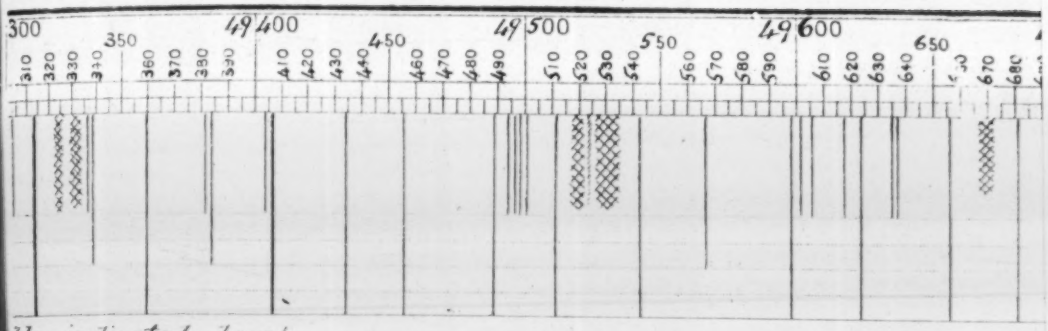
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BLUE BAND 2 Sept. 27, 1883. Casella's 0".5 Press.



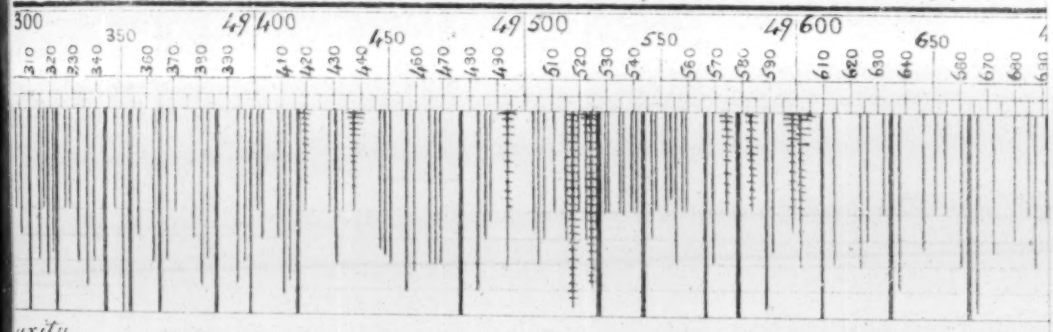
BLUE BAND. 1 (Cont^d) — Primary.

-CUUM - TUBE



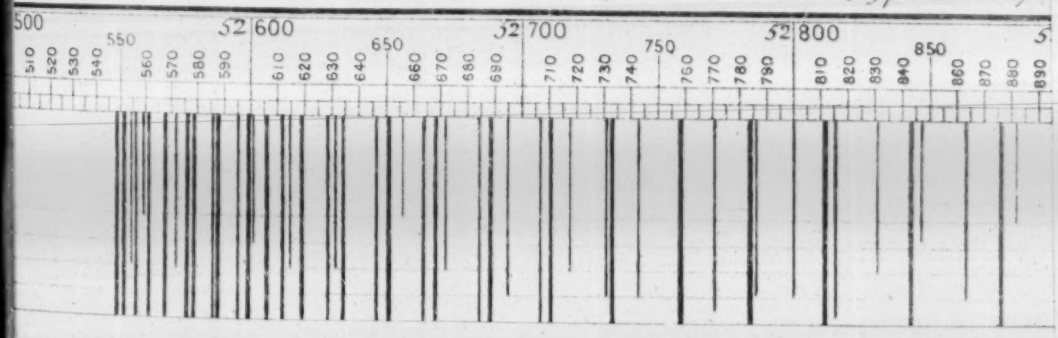
ly indicated here!

Prof. Rowland's Grating 5th order of Spectrum. Mag. power

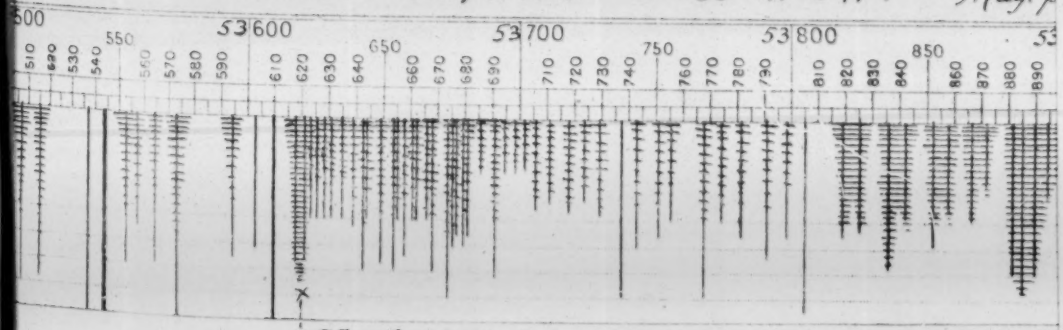


urity.

Casella's 0".5 Press. CO tube. Prismatic Disp. = 60° A to H. Mag p. = 21. Defu



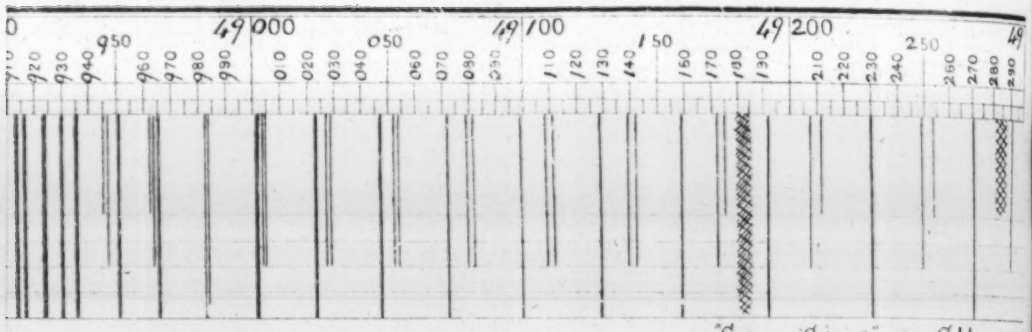
CO tube. Prismatic Dispersion = 60° A to H. Mag.



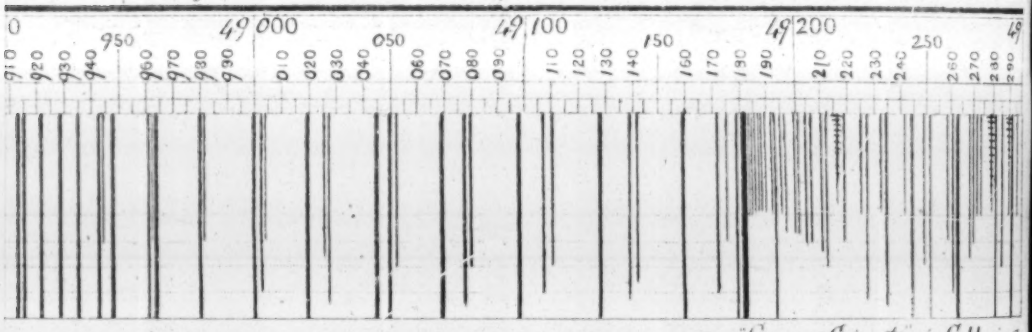
× Blue band of CH impurity enters here.

Photo-lith 1884

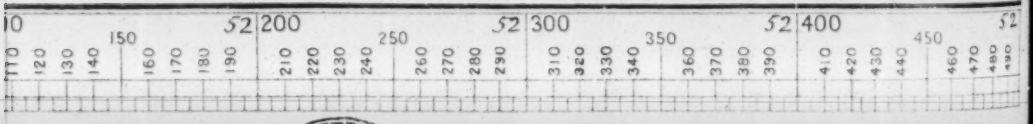
CO IN VA-



ND. ♀ Aug. 10, 1883. Casella's CO tube at 0·1 Pressure.

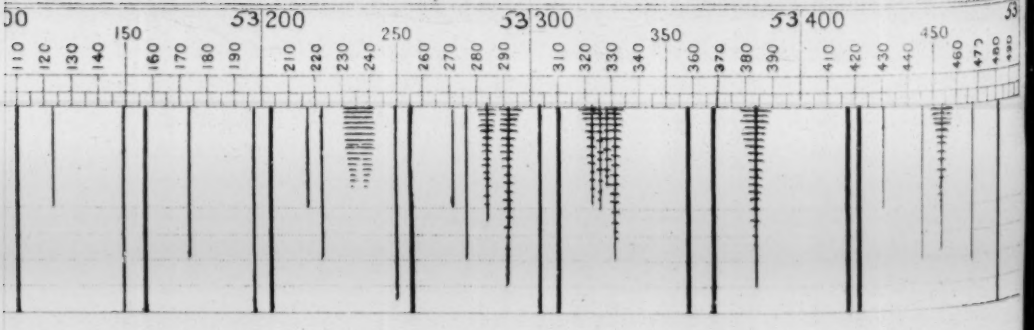


AND. ☾ Sept. 24, 1883. Green CO intruded into by Green CH, in



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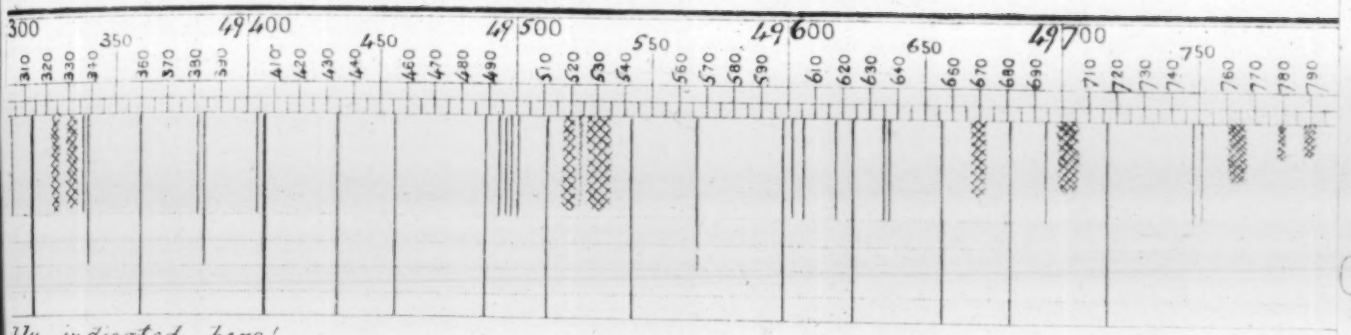
BAND 2 Sept. 27, 1883. Casella's 0·5 Press.



ND. 1 (Cont'd) — primary.

A. Ritchie & Son.

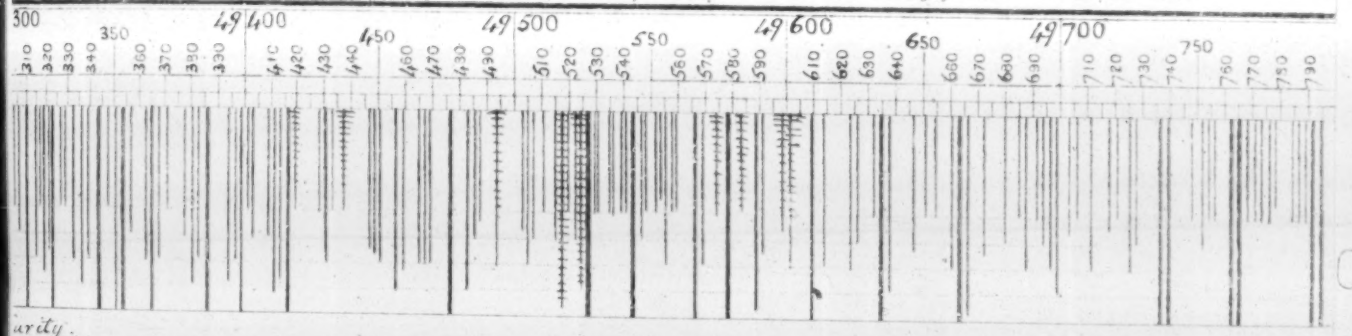
-CUUM - TUBE



CO

kly indicated here!

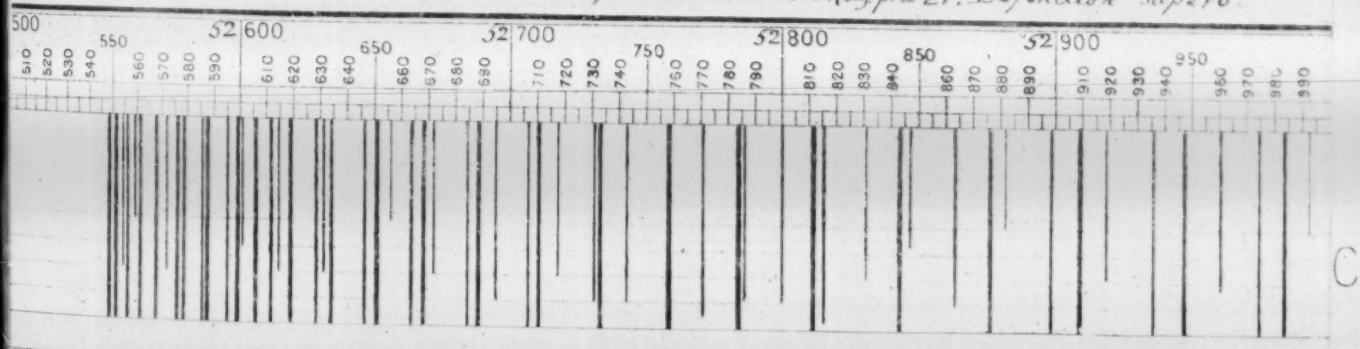
Prof. Rowland's Grating 5th order of Spectrum. Mag. power = 21.



CO

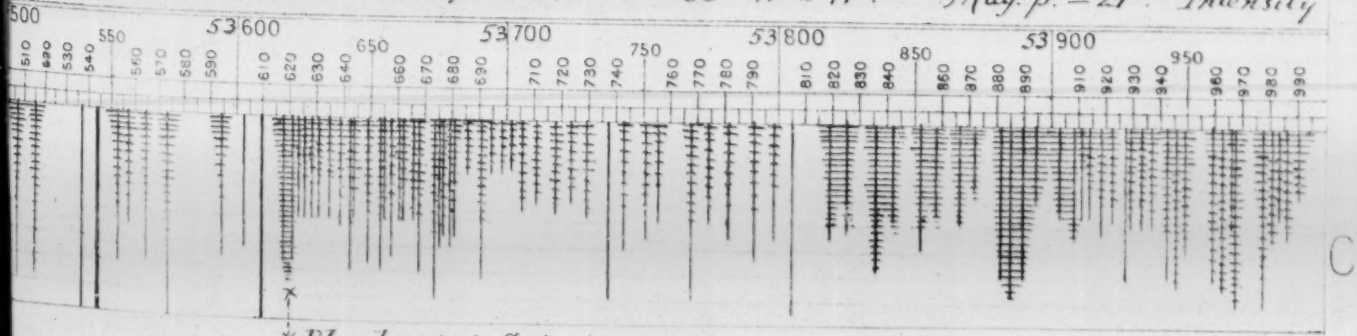
urity.

Casella's 0"5 Bress CO tube. Prismatic Disp. = 60° A to H. Mag p. = 21. Definition superb.



CO

CO tube. Prismatic Dispersion = 60° A to H. Mag. p. = 21. Intensity



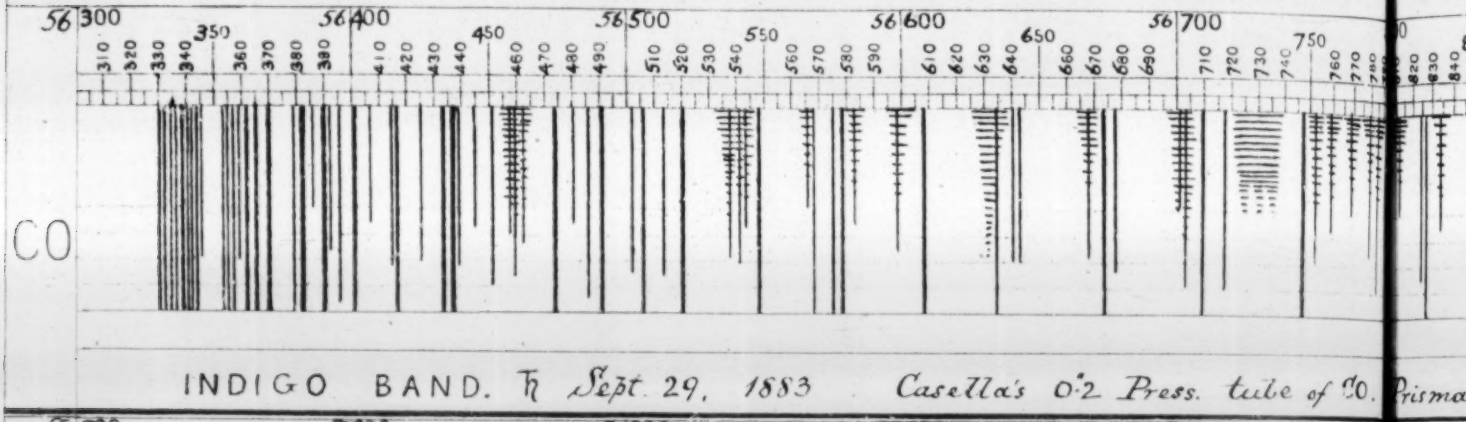
CO

× Blue band of CH impurity enters here.

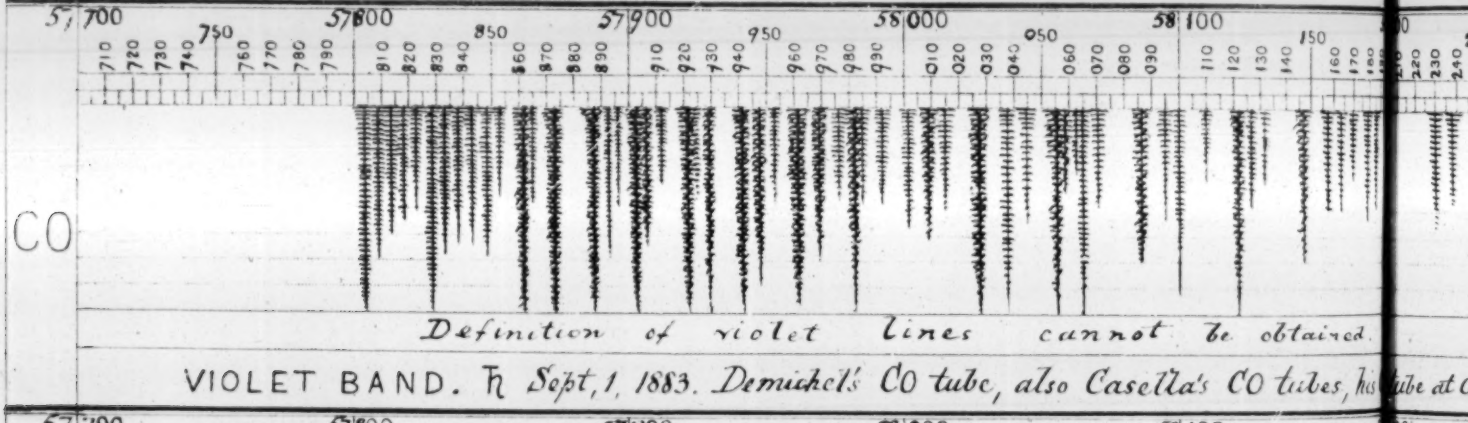
Photo-Lith 1894

T. H. del.

CO IN VA-C

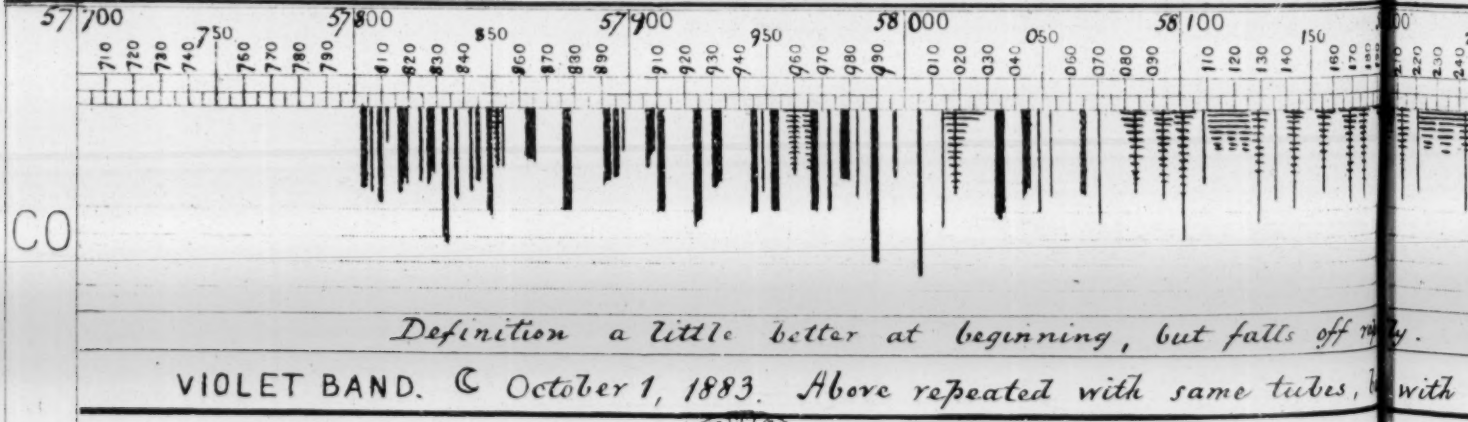


INDIGO BAND. ℏ Sept. 29, 1883. Casella's 0·2 Press. tube of CO. Prisma



Definition of violet lines cannot be obtained.

VIOLET BAND. ℏ Sept, 1, 1883. Demichel's CO tube, also Casella's CO tubes, his tube at C



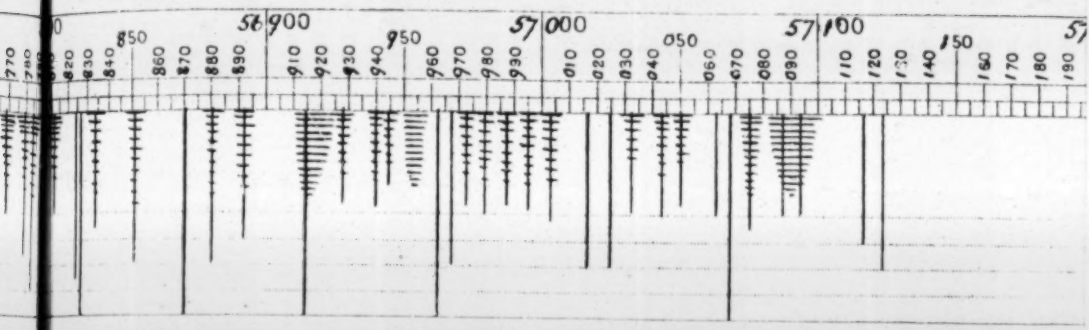
Definition a little better at beginning, but falls off rapidly.

VIOLET BAND. ☾ October 1, 1883. Above repeated with same tubes, with

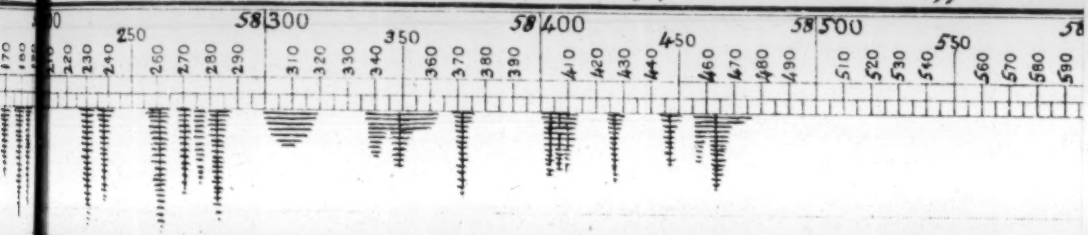
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CO

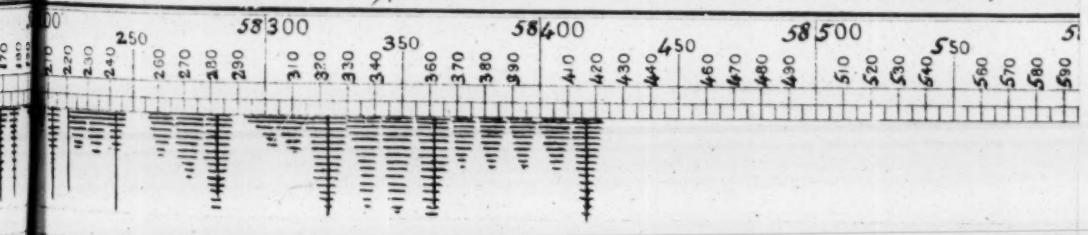
A-CUUM - TUBE



CO. Prismatic Dispersion = 48° A to H, Mag. power = 21. Lines difficult an



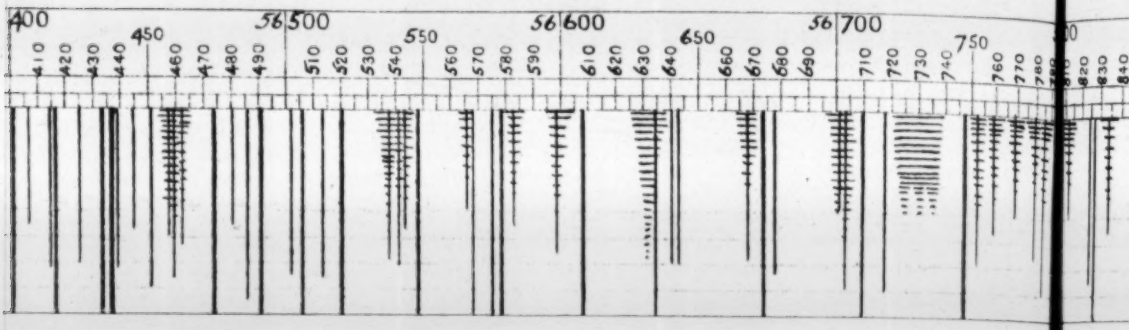
his tube at 01 press. (strong in CO), and his $CO+CO^2$ tube at 0"3 Press. Small plates



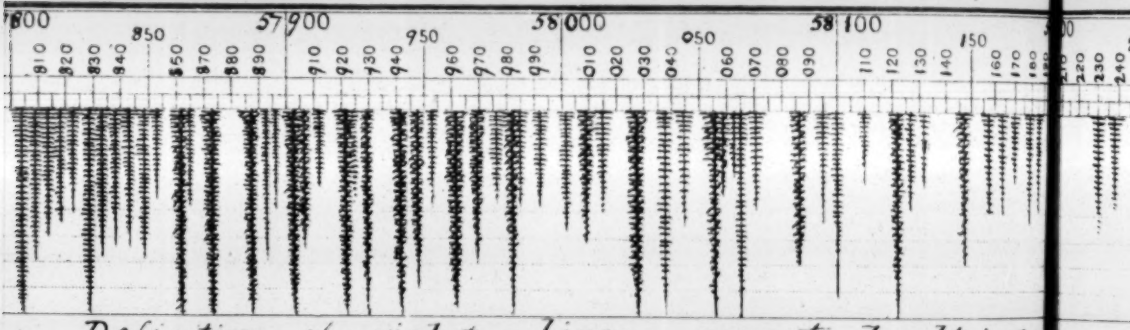
with larger plates in Battery, & sparks increased from 2" to 3" long. Definit

Photo-lith 1884

CO IN VA-C

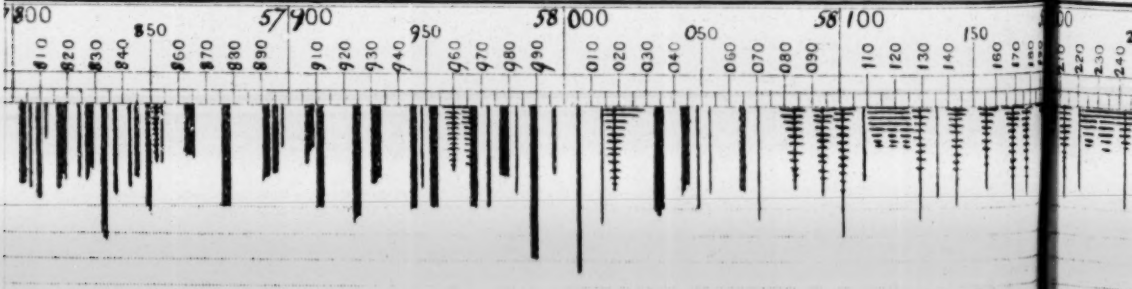


BAND. ℏ Sept. 29, 1883 Casella's 0·2 Press. tube of CO. Prisma



Definition of violet lines cannot be obtained.

BAND. ℏ Sept, 1, 1883. Demichel's CO tube, also Casella's CO tubes, his tube at C

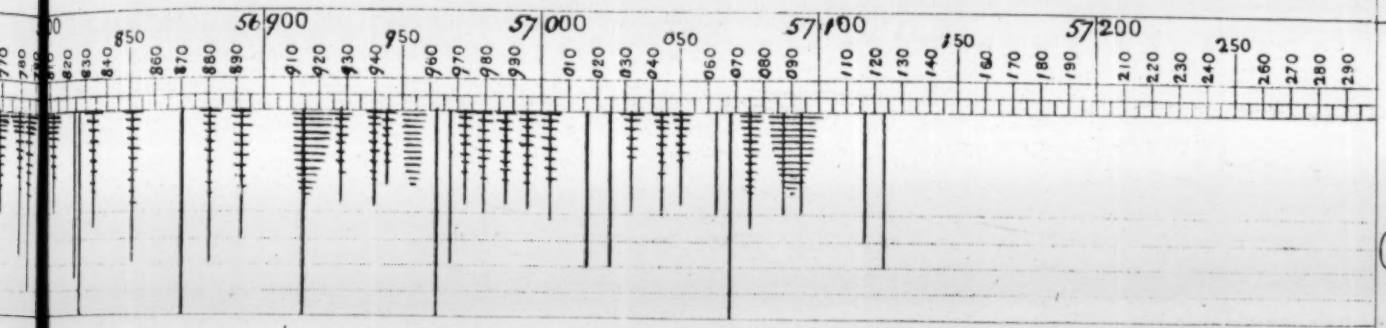


Definition a little better at beginning, but falls off rapidly.

AND. ☾ October 1, 1883. Above repeated with same tubes, with

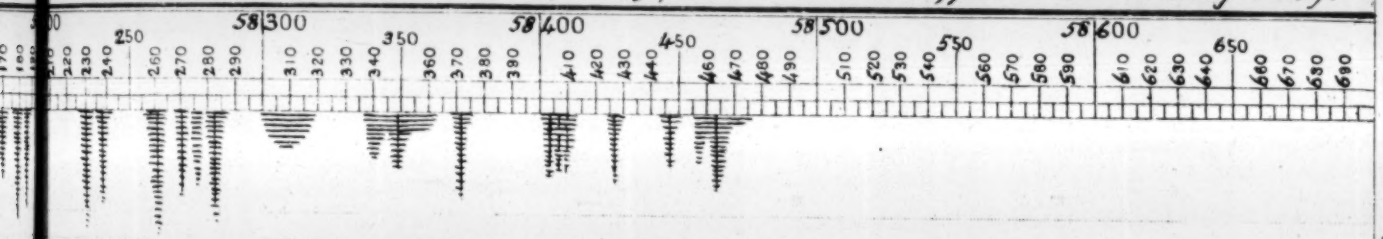
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A-CUUM - TUBE



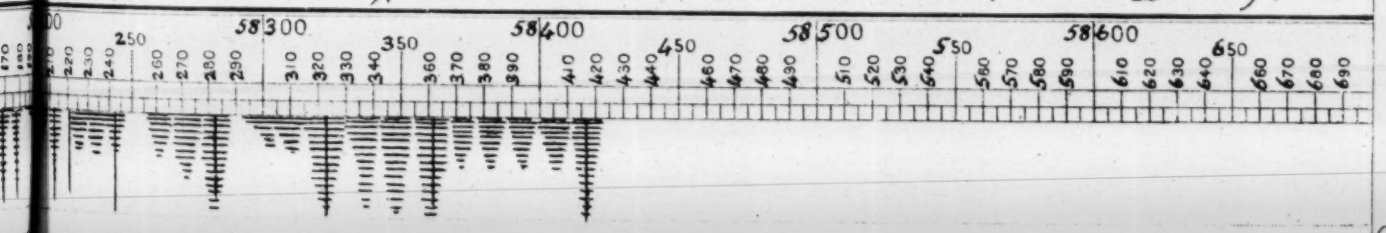
CO

Prismatic Dispersion = 48° A to H, Mag. power = 21. Lines difficult and becoming hazy.



CO

tube at 0'1 press. (strong in CO), and his $CO+CO^2$ tube at 0"3 Press. Small plates in Battery:

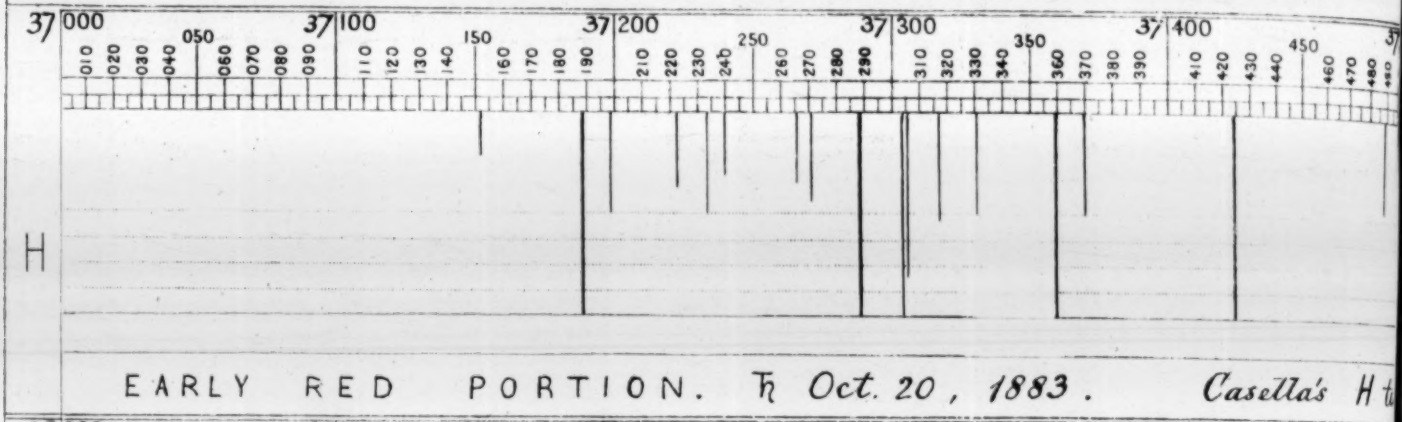


CO

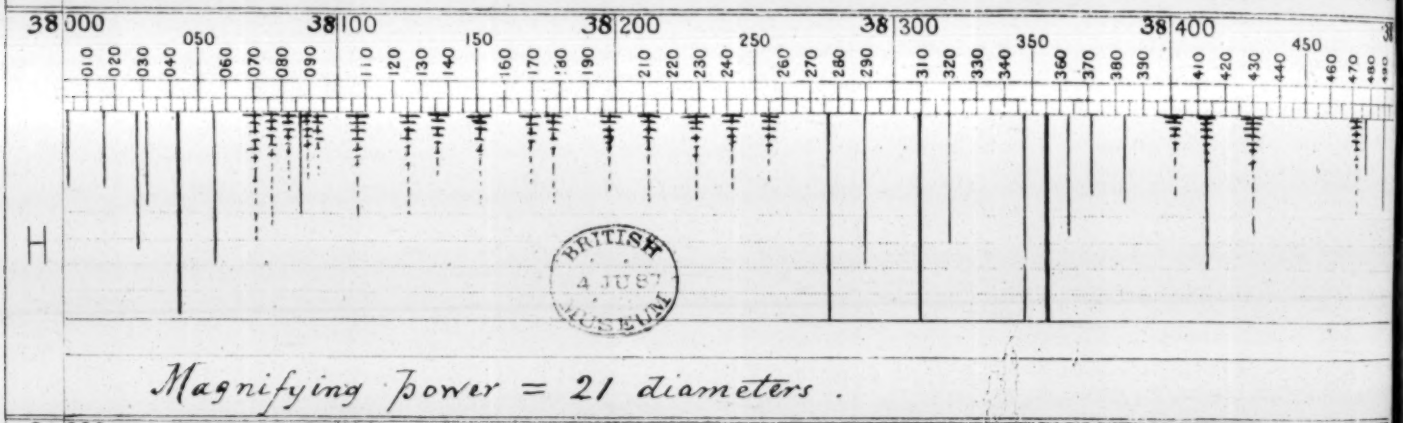
with larger plates in Battery, & sparks increased from 2" to 3" long. Definition distressingly bad

CO

H IN VAC-U

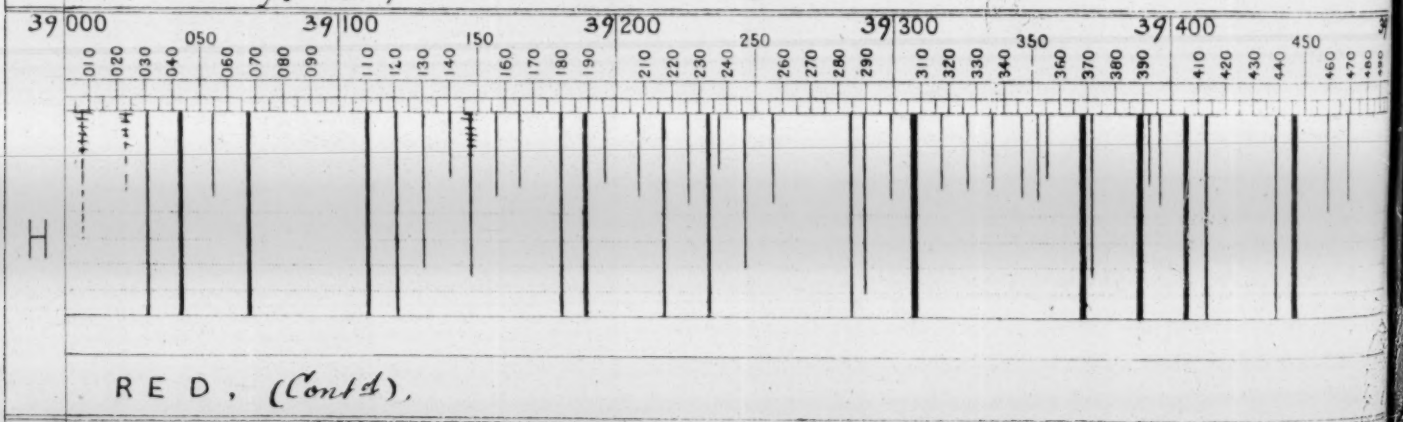


EARLY RED PORTION. ♄ Oct. 20, 1883. Casella's H tube, &c.

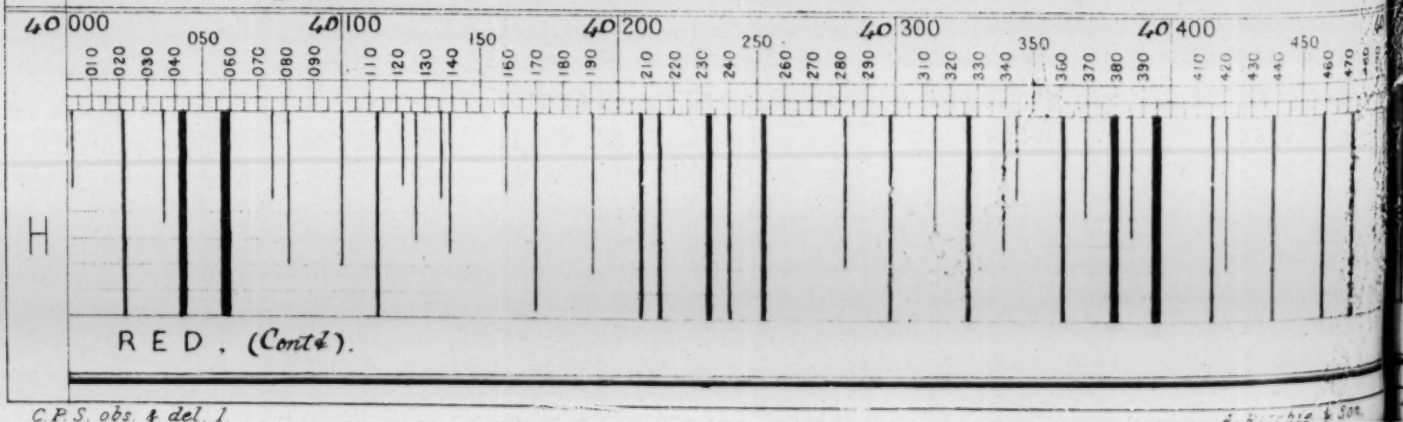


BRITISH 4 JUST MUSEUM

Magnifying power = 21 diameters.



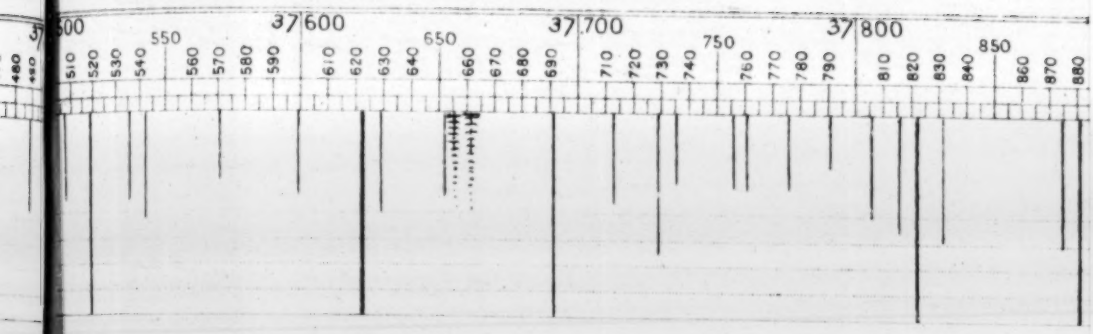
RED, (Cont'd).



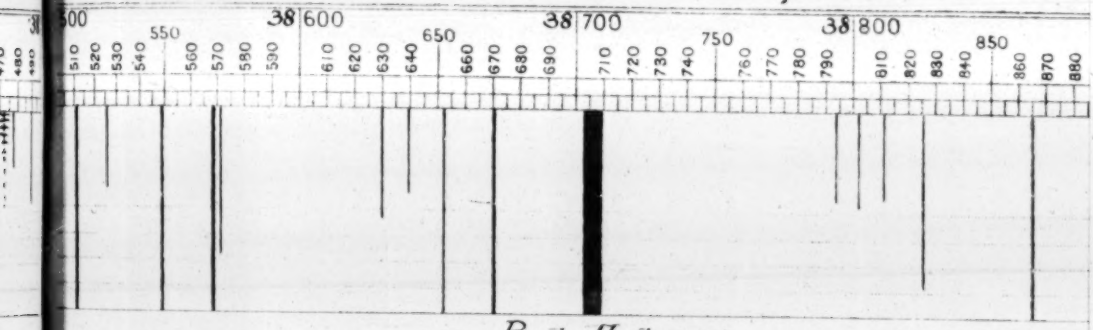
RED, (Cont'd).

A. Ritchie & Son. Photo-Li

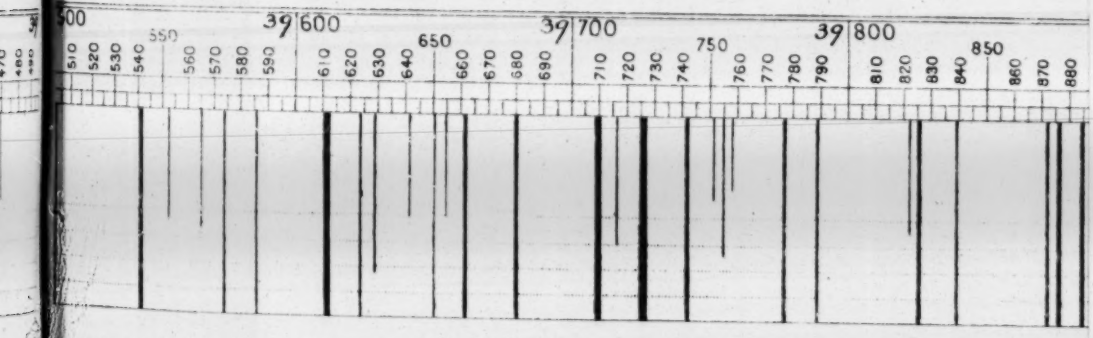
C-UUM - TUBES

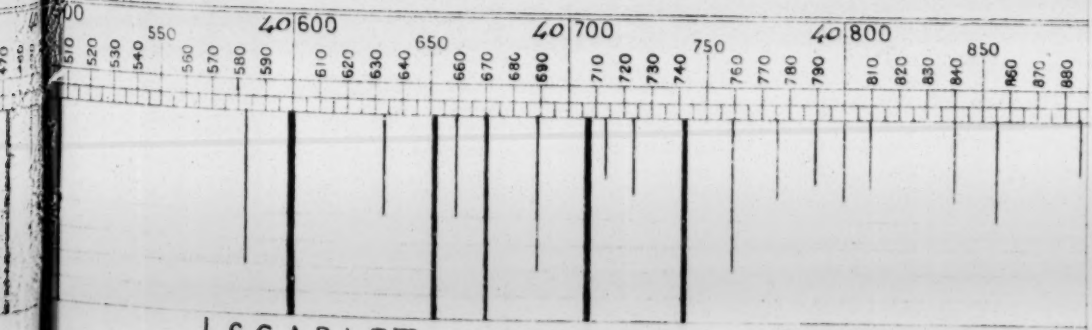


Tube, at pressure 0·4. *Prismatic Dispersion = 60°*



Red Hydrogen.

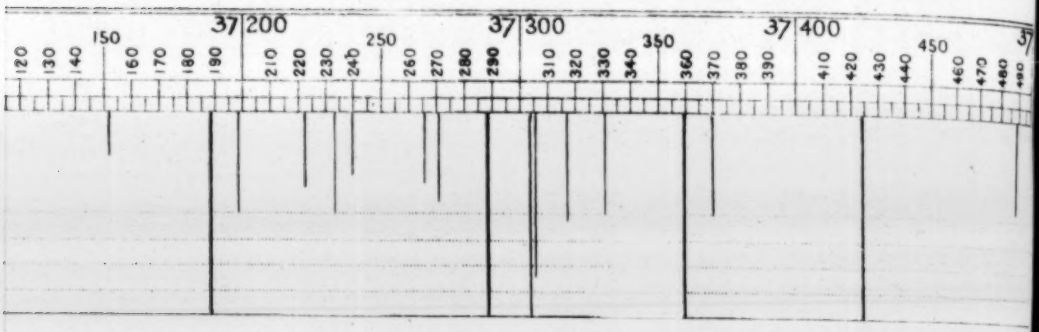




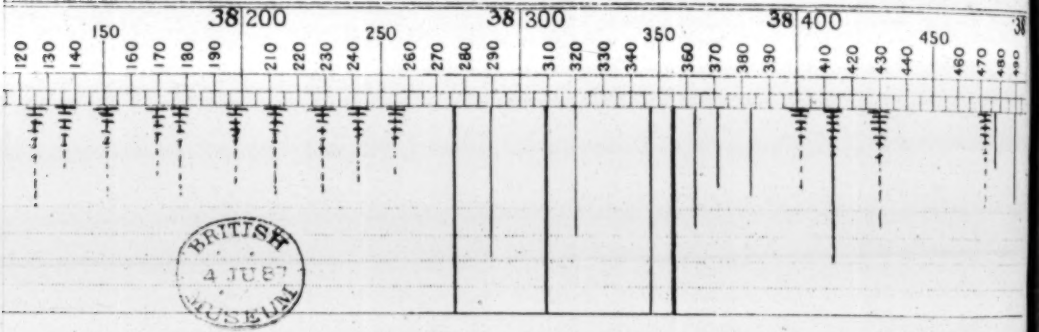
SCARLET TO ORANGE. ♂ 16ª October 18

Photo-lith. 1884

H IN VAC-U

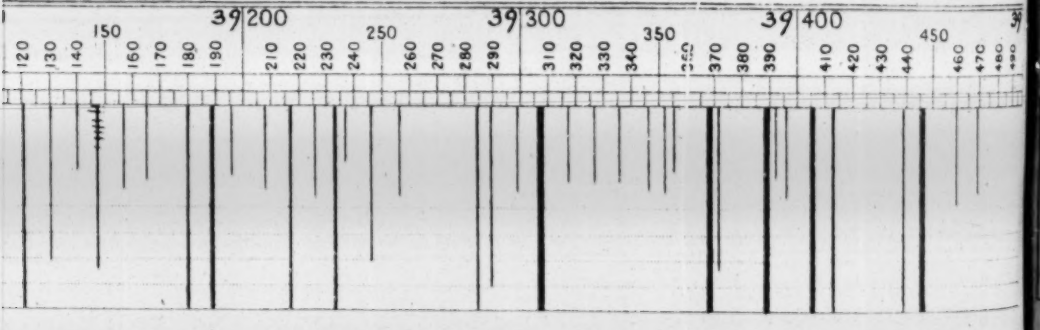


D PORTION. ♄ Oct. 20, 1883. Casella's H tube,



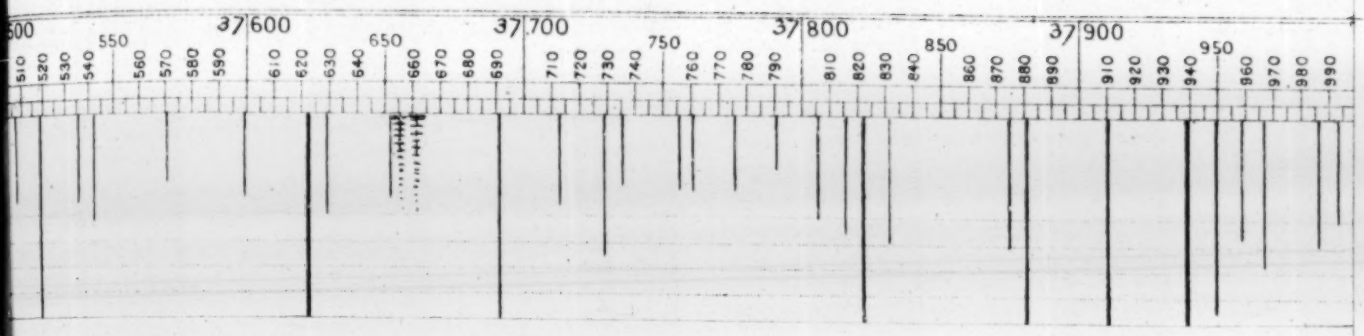
BRITISH
4 JUE
MUSEUM

Power = 21 diameters.



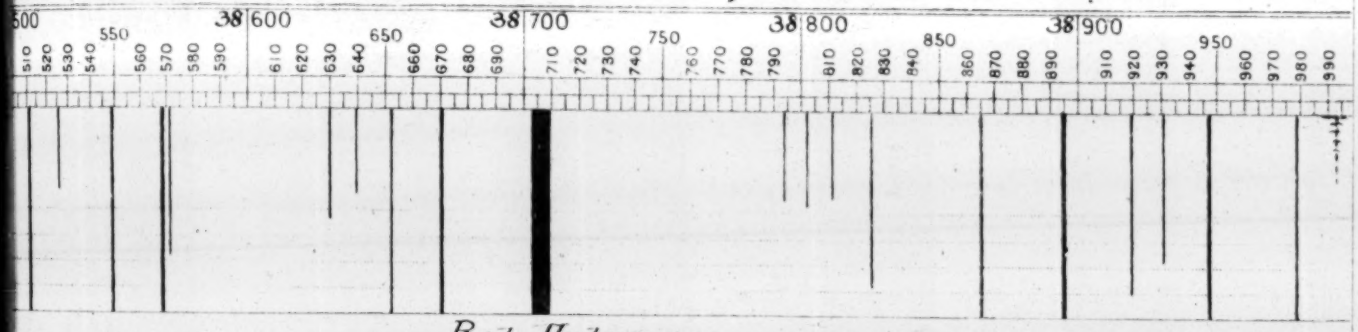


C-UUM - TUBES



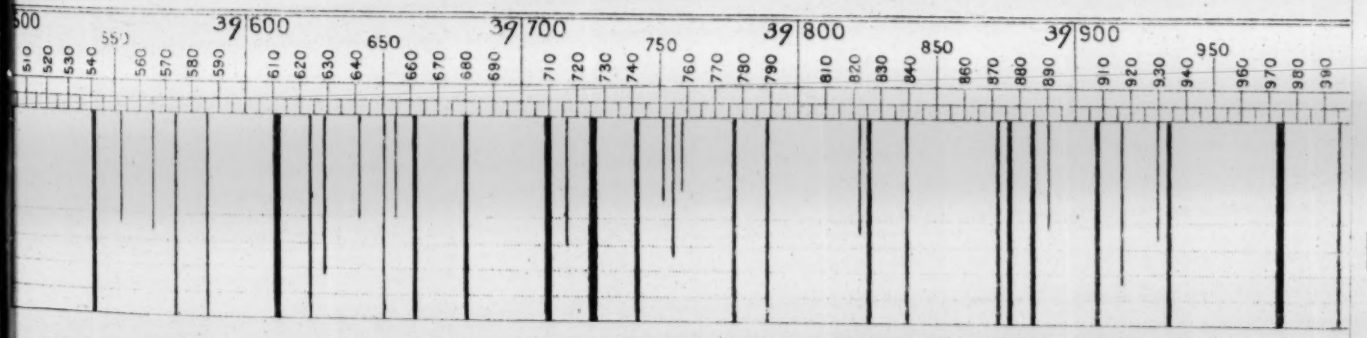
H

H tube, at pressure 0"4. Prismatic Dispersion = 60° A to H.

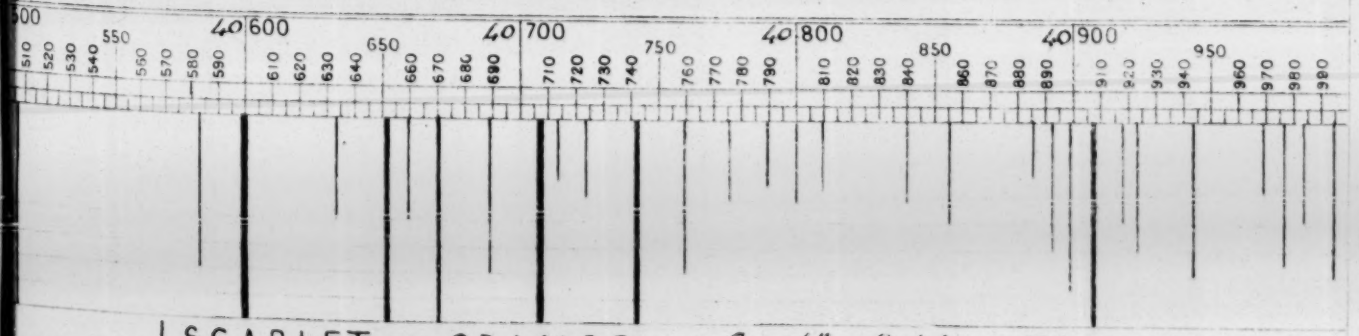


H

Red Hydrogen.



H



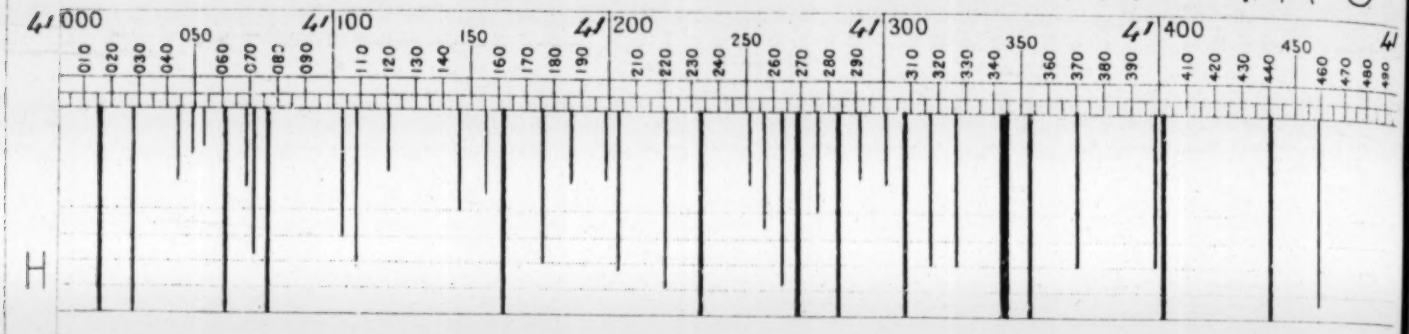
H

SCARLET to ORANGE. 8 16h October 1883.

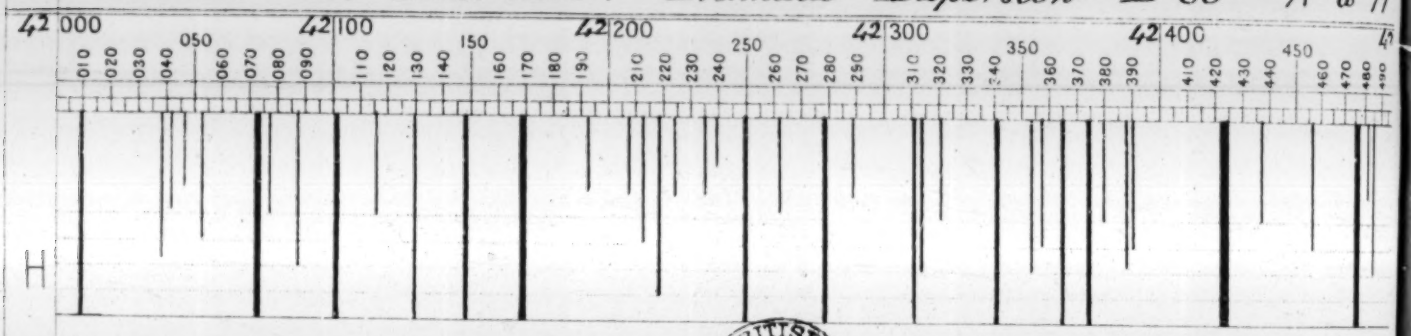
Photo-Lith 1884

T H del 2

H IN VAC-U

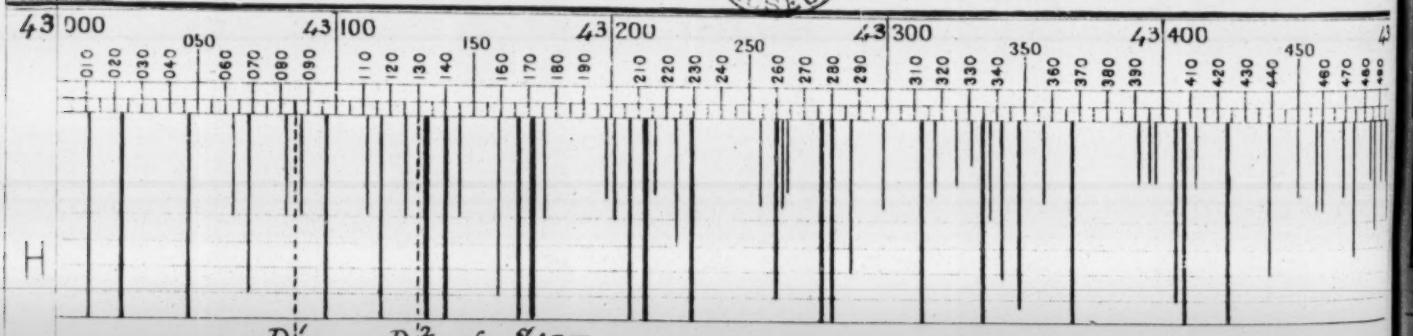


Casella's 0·4 Press. tube. Prismatic Dispersion = 60° A to H



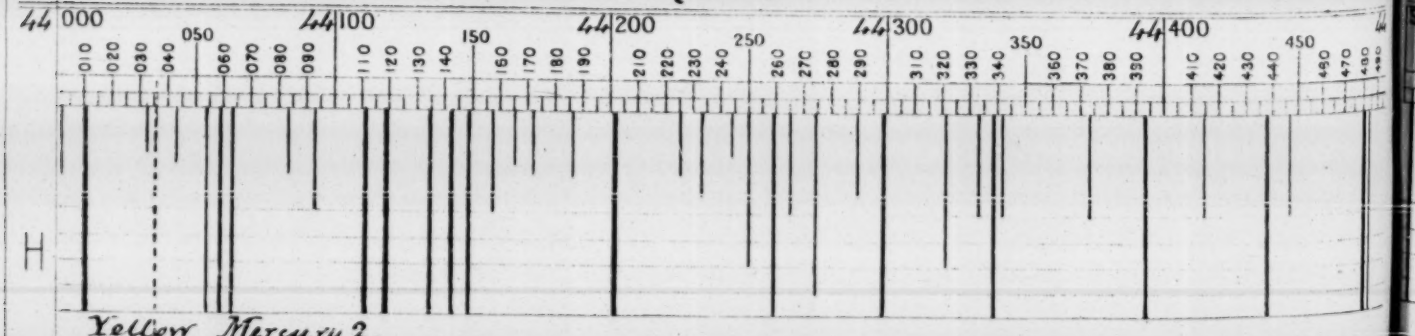
SCARLET TO ORANGE, (Cont^d.)

BRITISH MUSEUM 4 JUN



D^1 D^2 of SALT.

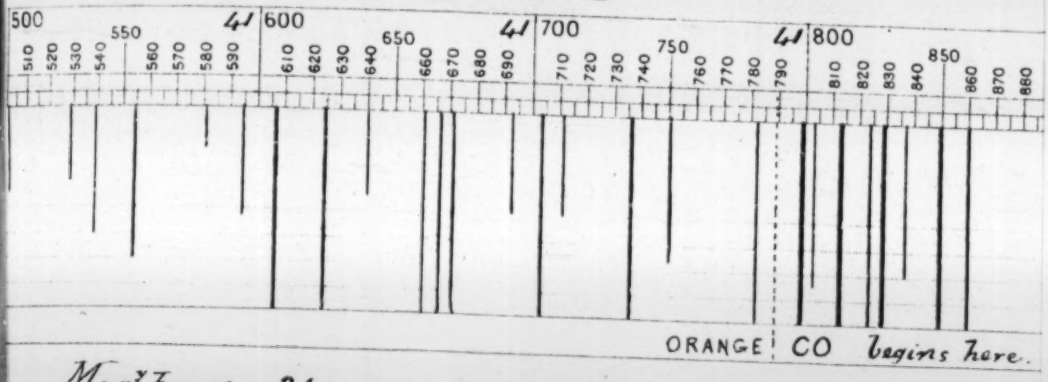
ORANGE TO YELLOW, (Cont^d).



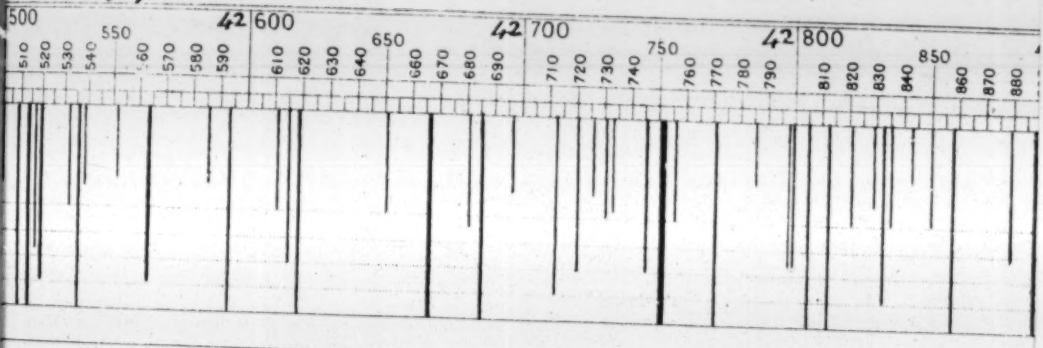
Yellow Mercury 2.

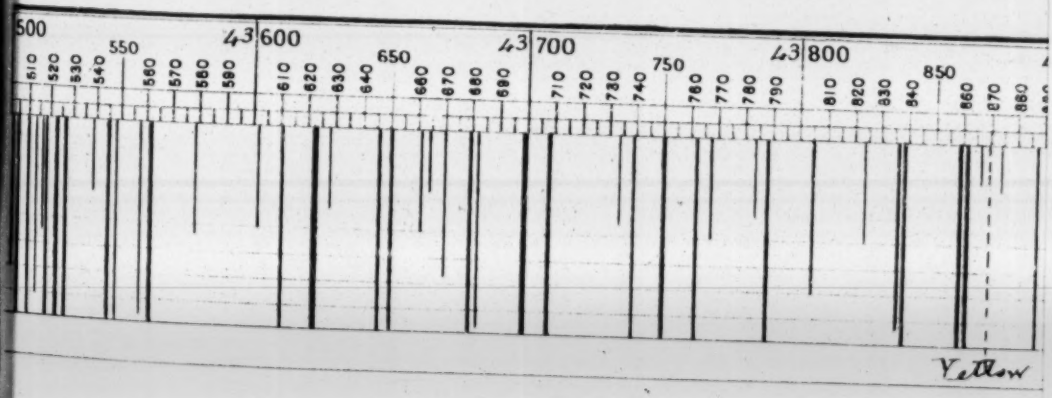
OR. TO YELLOW, (Cont^d). | YELLOW TO CITRON.

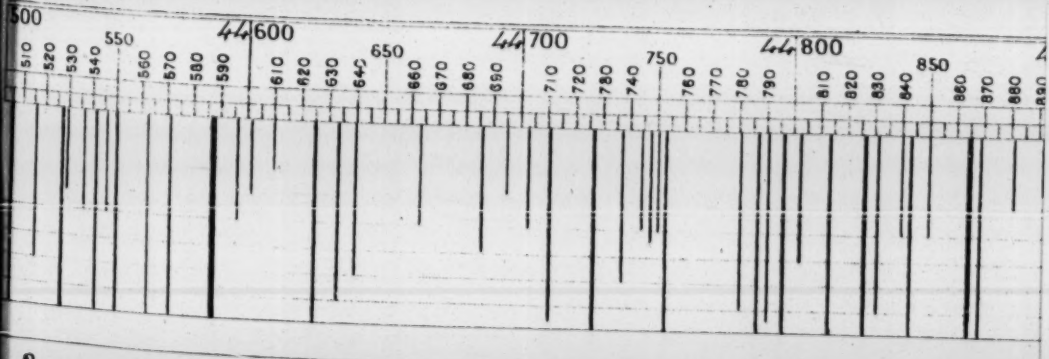
-UUM - TUBES



Mag.r Power = 21.



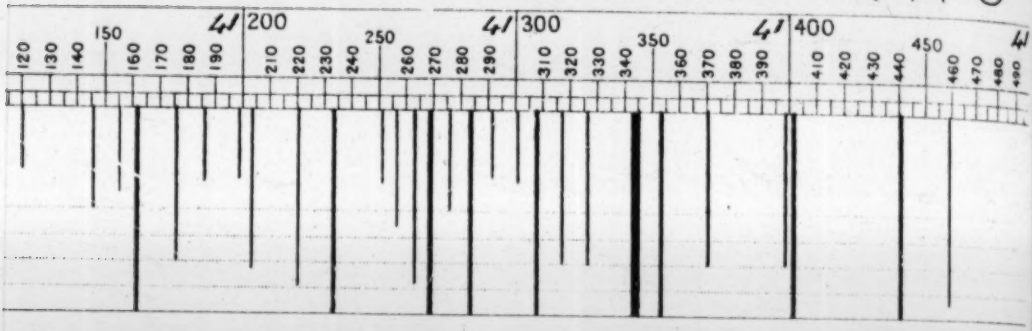




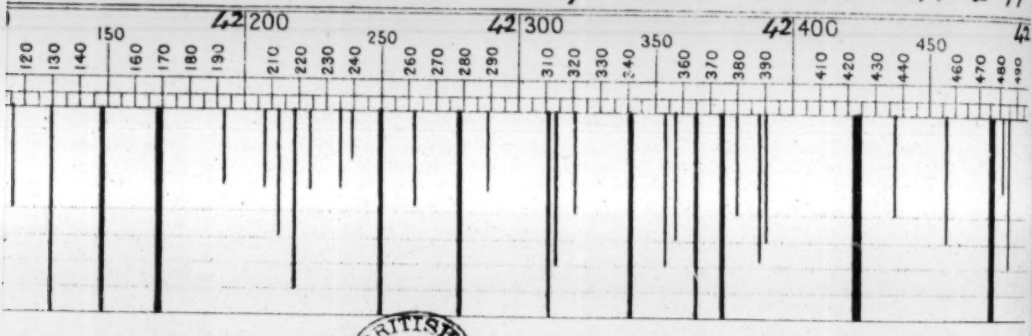
2. October 25, 1883. Casella's H tube at 0.4 Pressu

Photo-lith 1884.

H IN VAC-

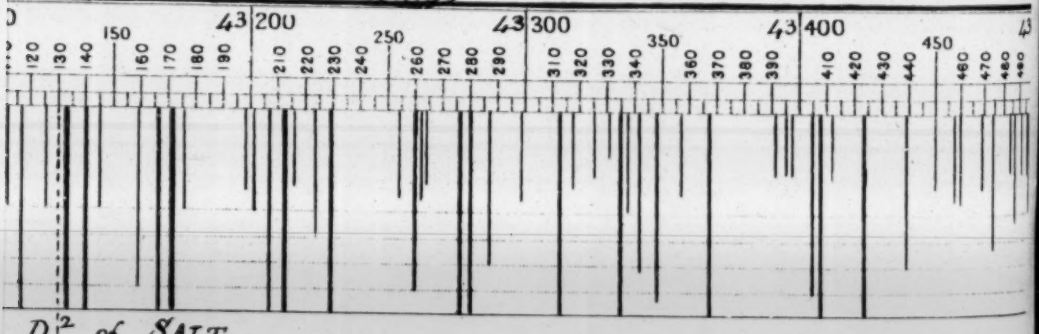


Press. tube. Prismatic Dispersion = 60° A to H



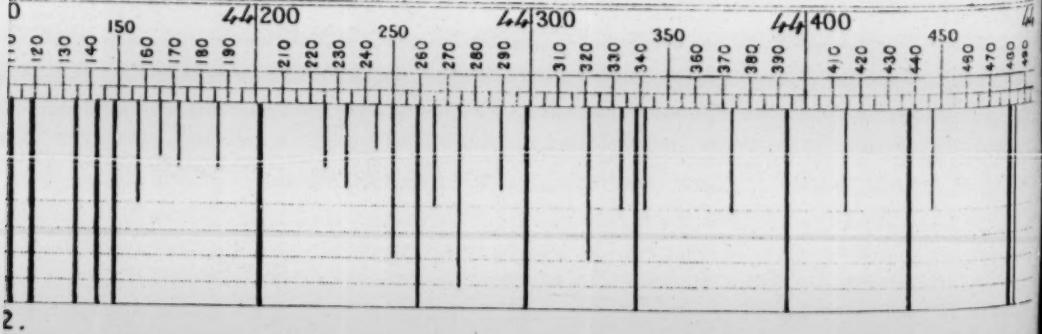
ORANGE, (Cont^d.)

BRITISH
4 JUN 87
MUSEUM



D^2 of SALT.

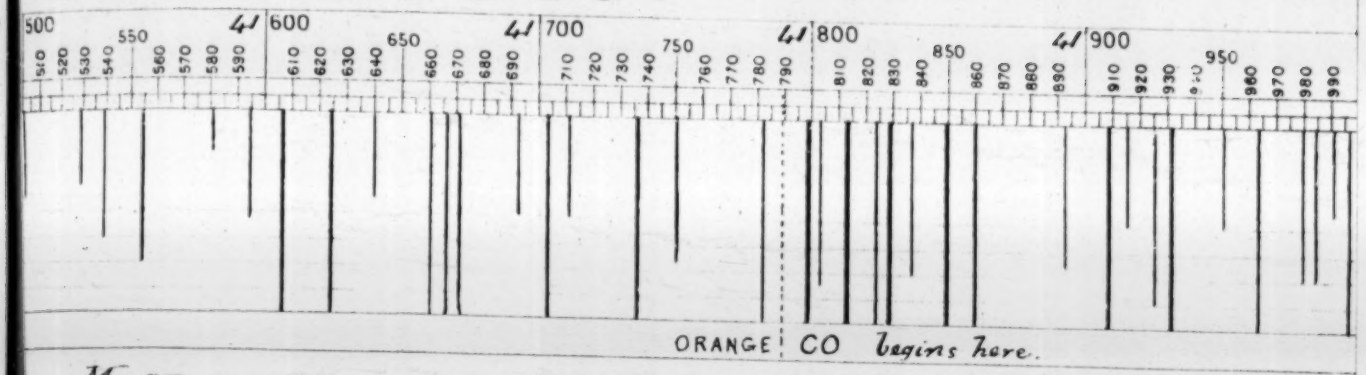
YELLOW, (Cont^d).



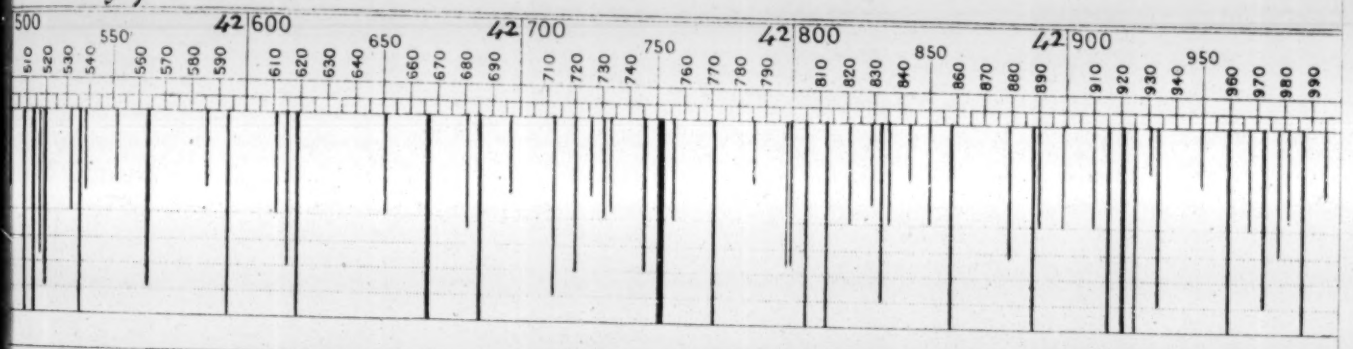
Cont^d). YELLOW TO CITRON.

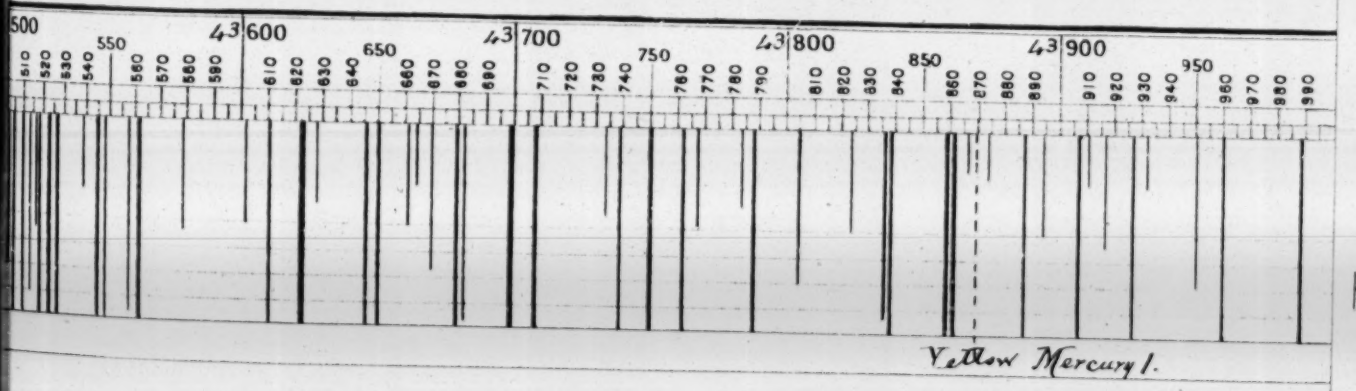
A. Ritchie & Son.

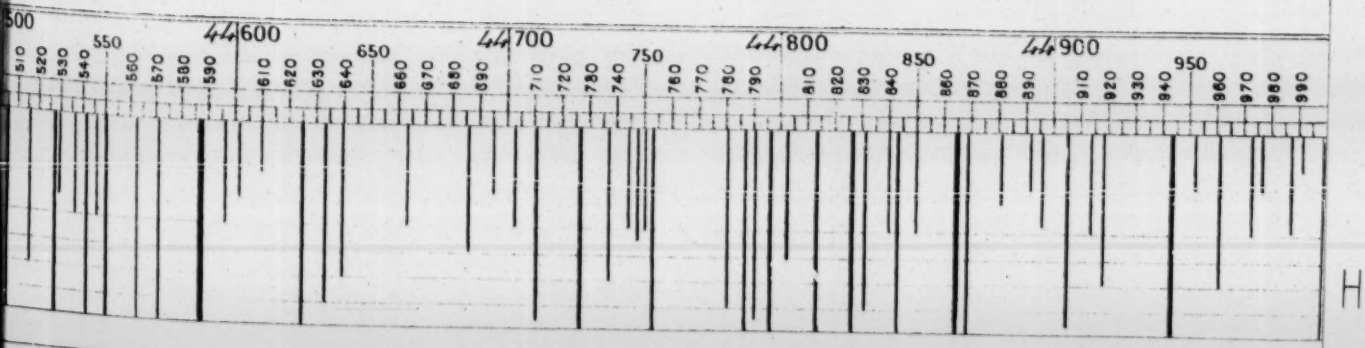
C-UUM - TUBES



Mag.ᶻ Forces = 21.







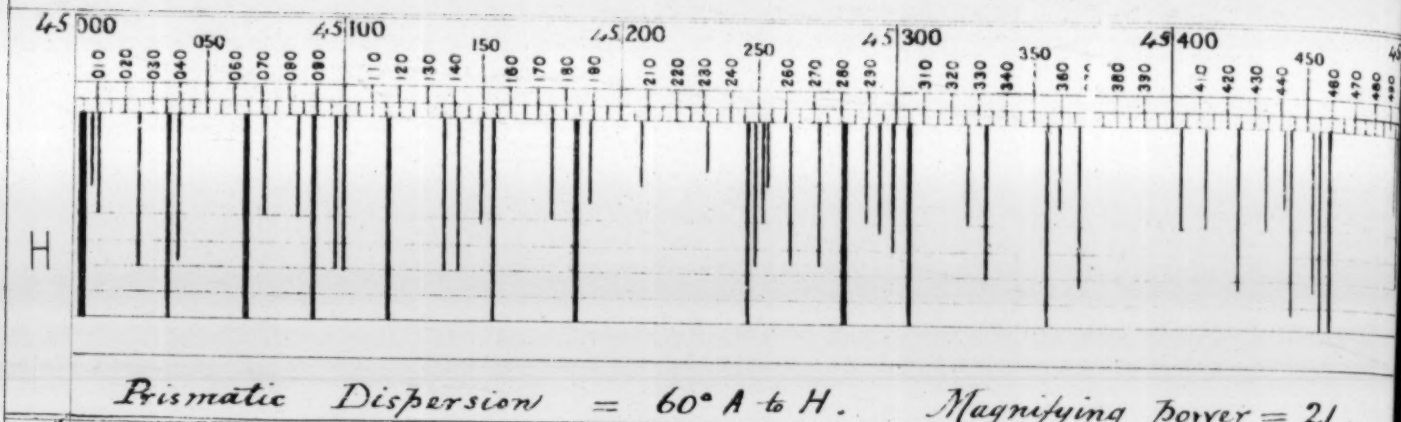
H H H H

4 October 25, 1883. Casella's H tube at 0·4 Pressure.

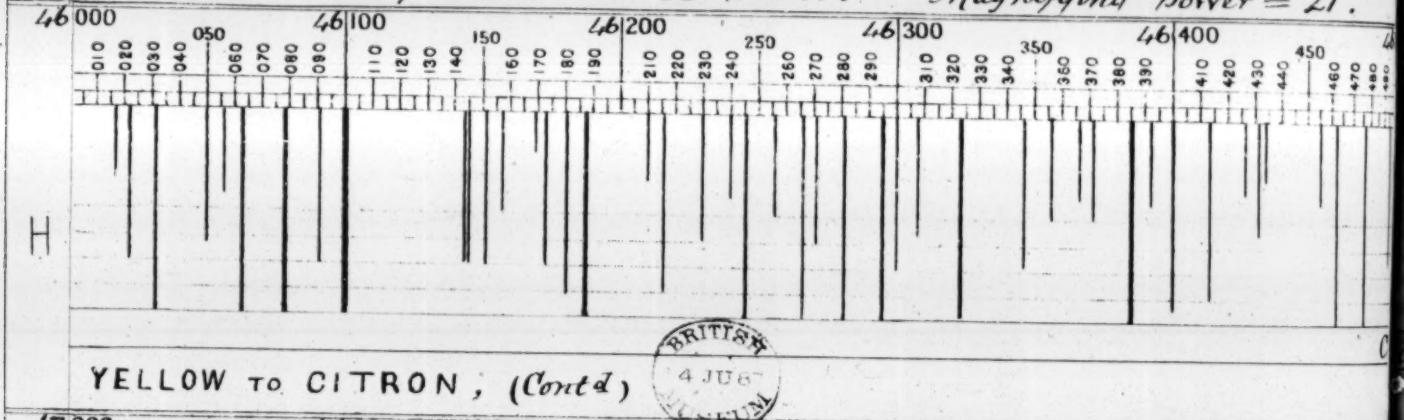
Photo-Lith. 1884

T H del 2

H IN VAC-U

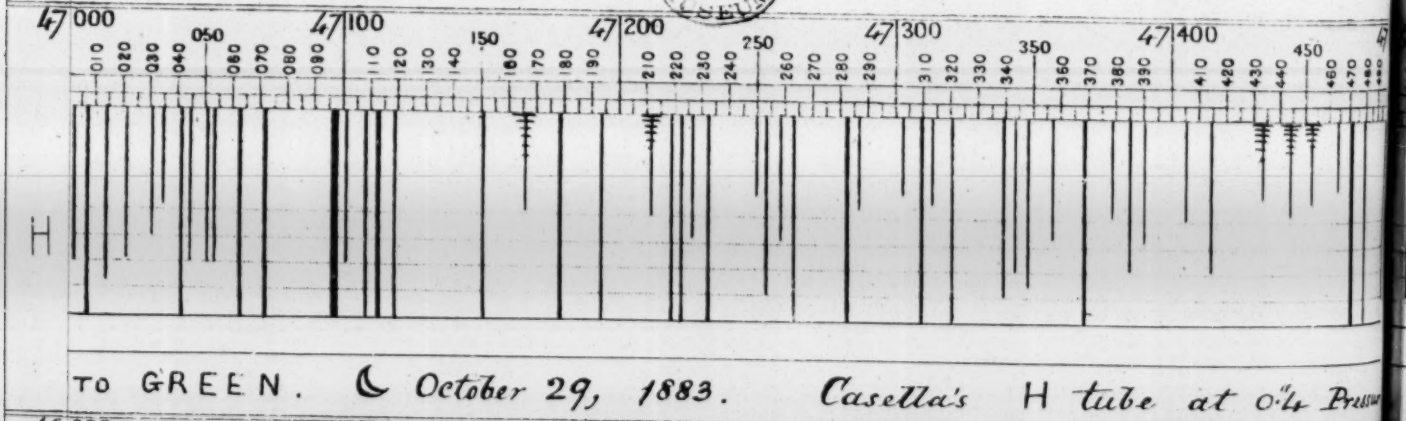


Prismatic Dispersion = 60° A to H. Magnifying Power = 21.

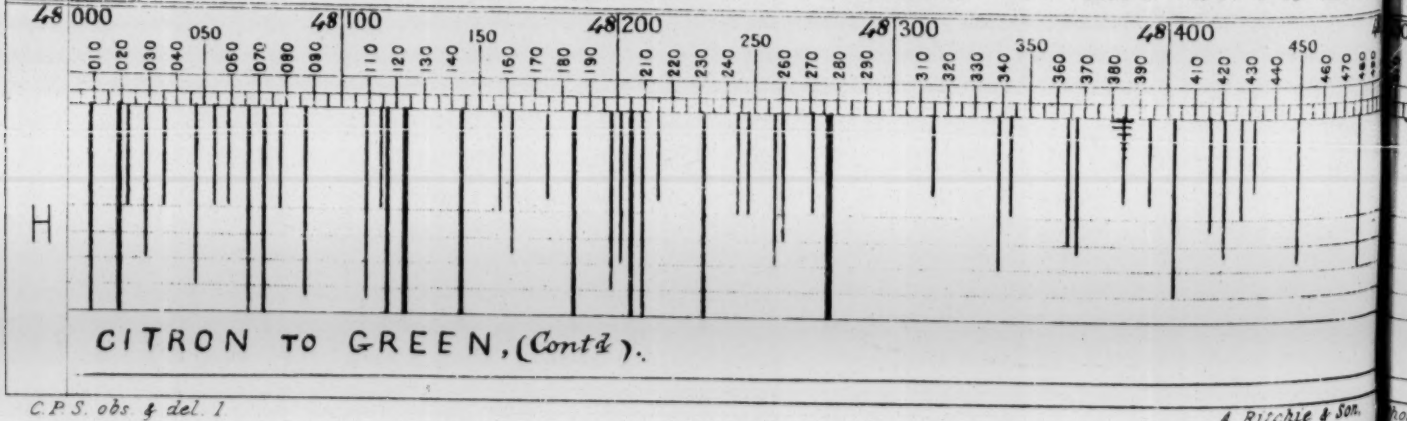


YELLOW TO CITRON, (Cont'd)

BRITISH
4 JU6
MUSEUM

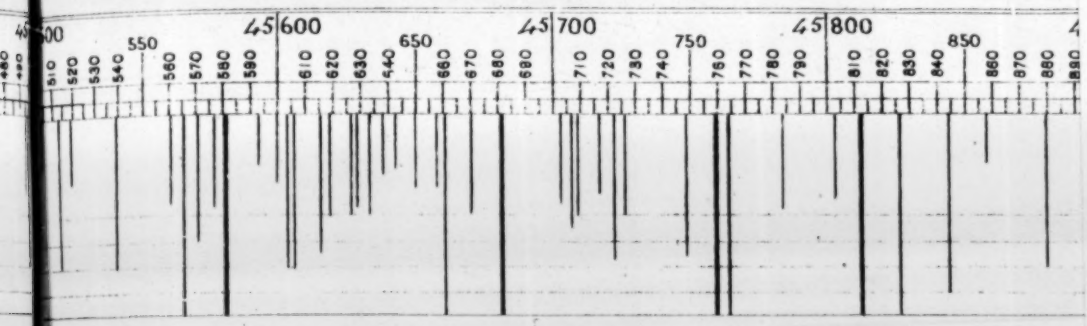


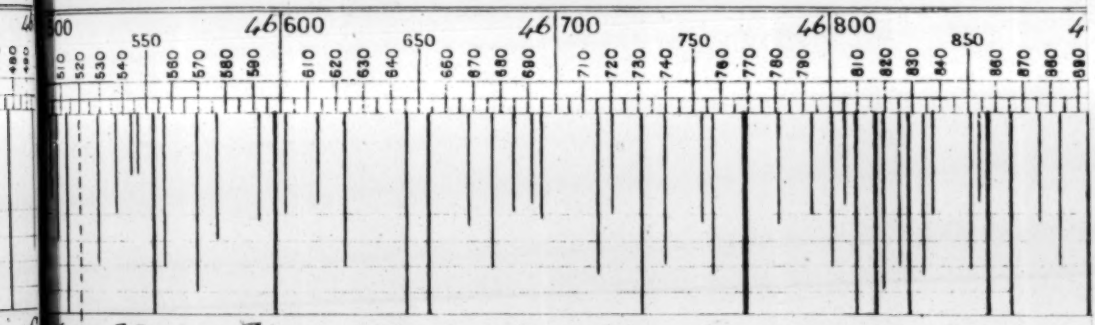
TO GREEN. ☾ October 29, 1883. Casella's H tube at 0·4 Pressu



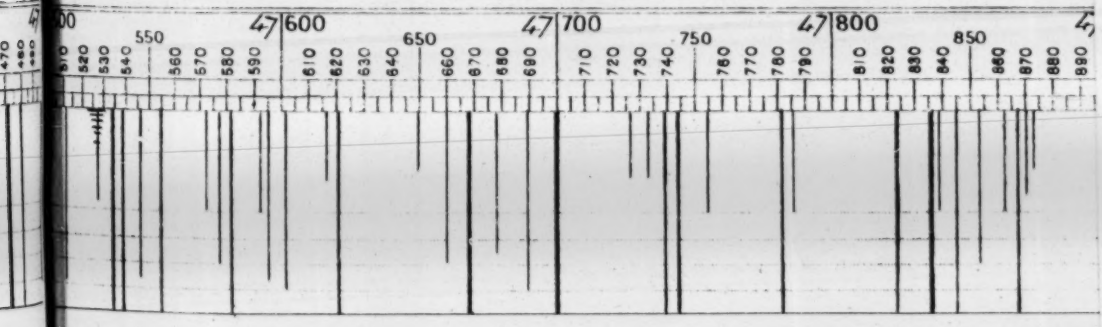
CITRON TO GREEN, (Cont'd).

-UUM - TUBES





Iron Mercury line.



Prismatic Dispersion = 60° A to H. Magnifying

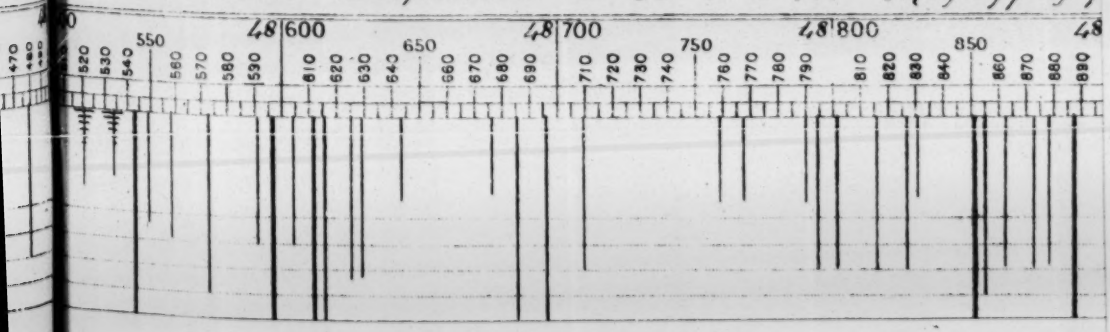
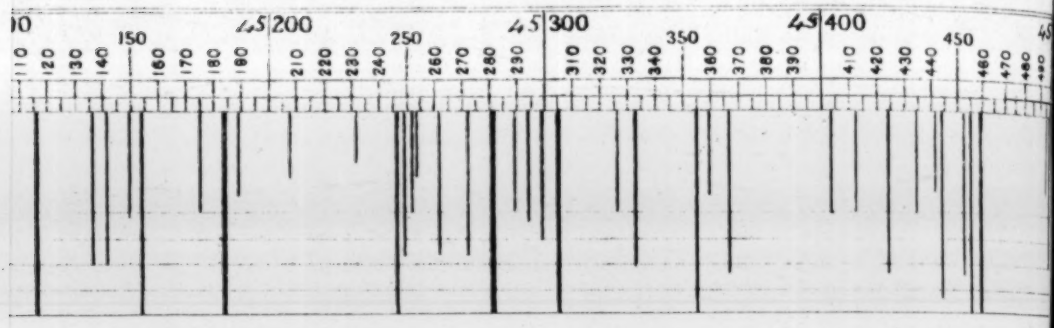
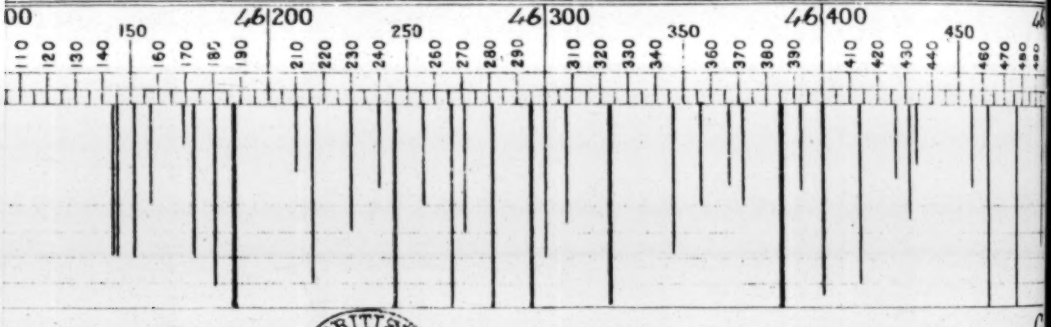


Photo-lith 1884

H IN VAC-U

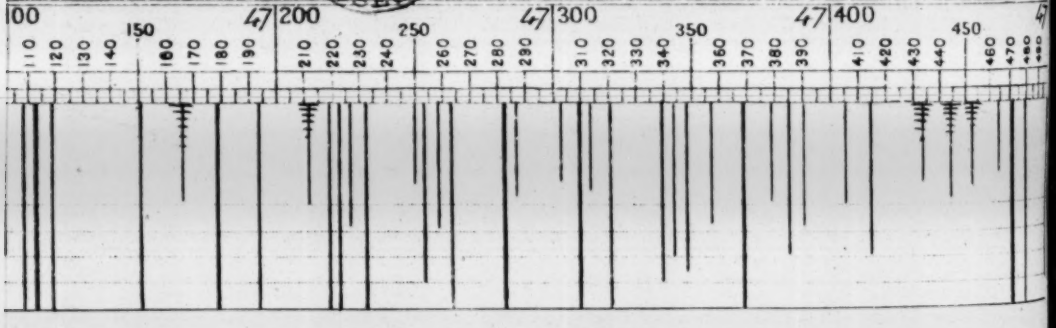


Dispersion = 60° A to H. Magnifying Power = 21.

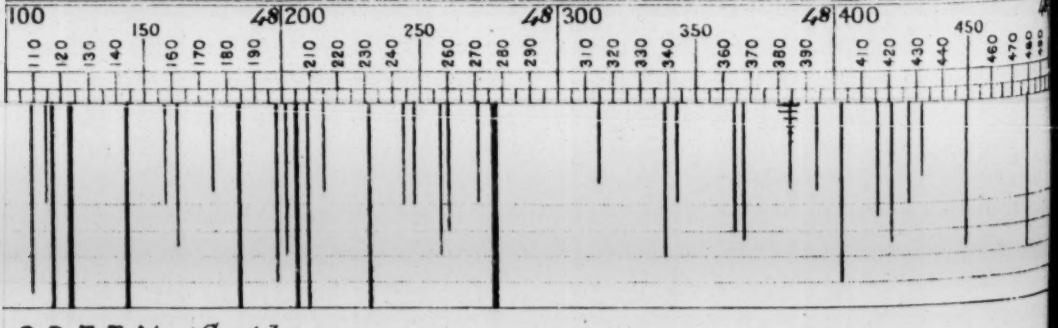


TRON, (Cont^d)

BRITISH
4 JUG
MUSEUM

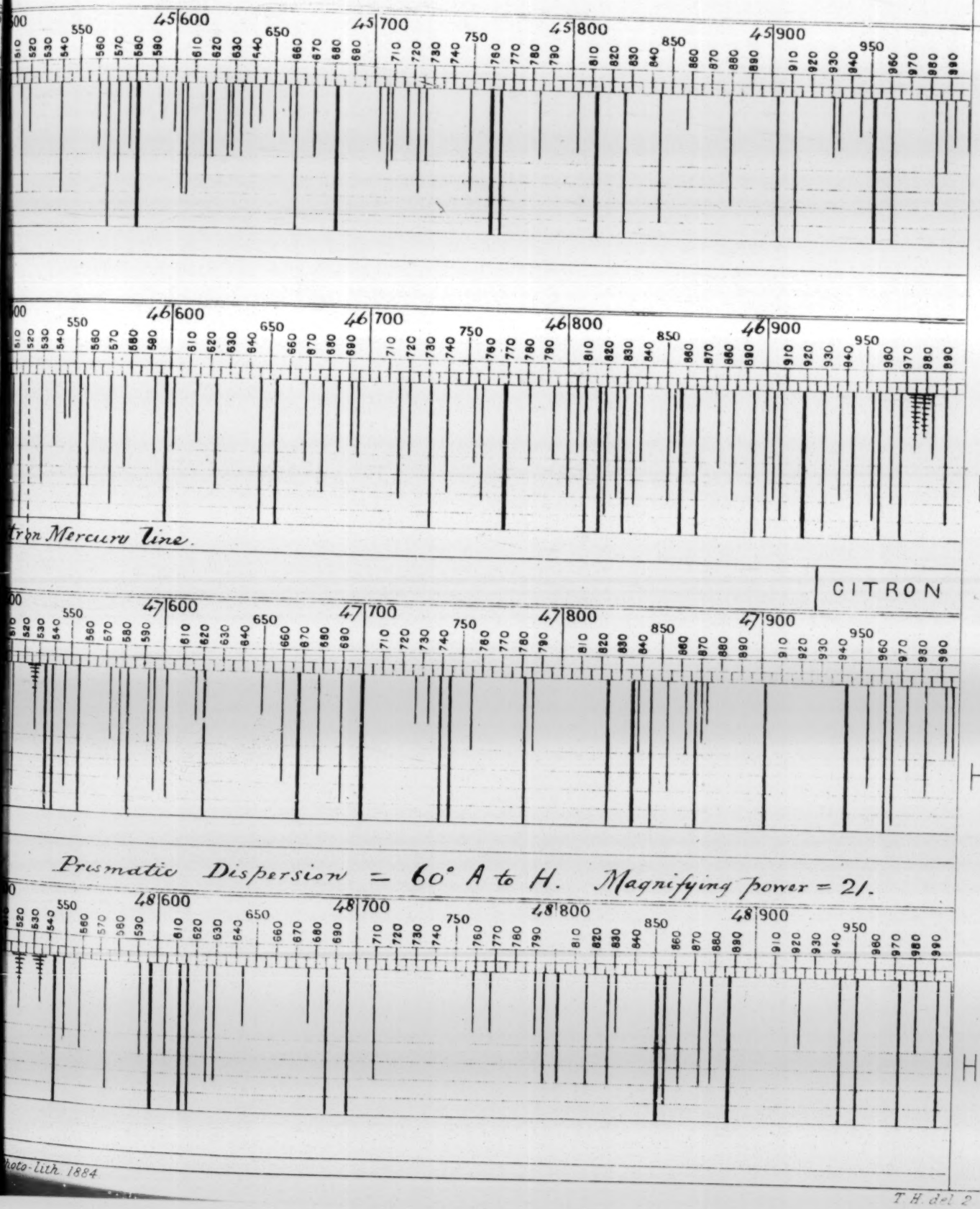


October 29, 1883. Casella's H tube at 0·4 Pressu



GREEN, (Cont^d).

C-UUM - TUBES



Citron Mercury line.

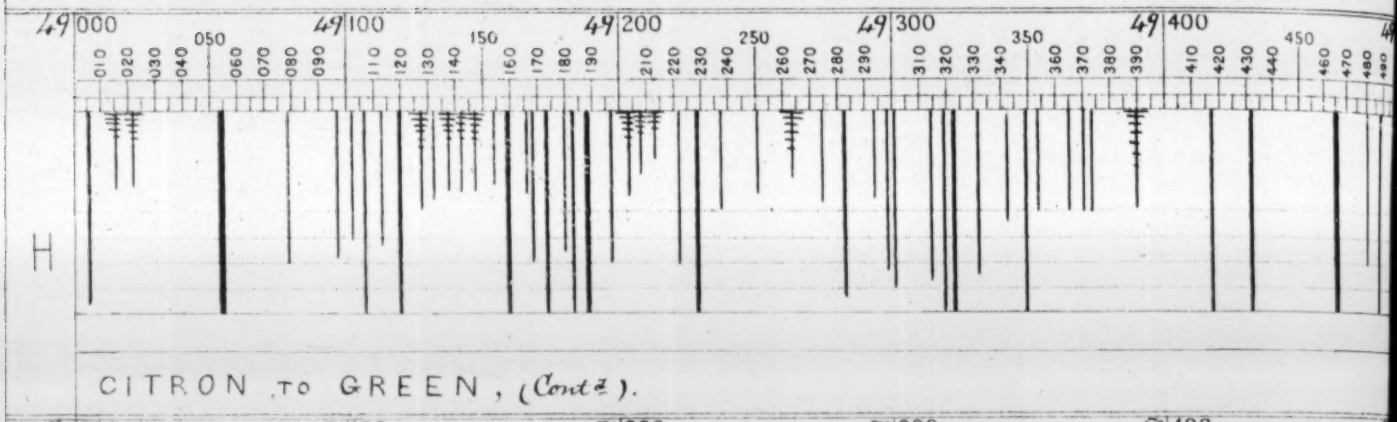
CITRON

Prismatic Dispersion = 60° A to H. Magnifying power = 21.

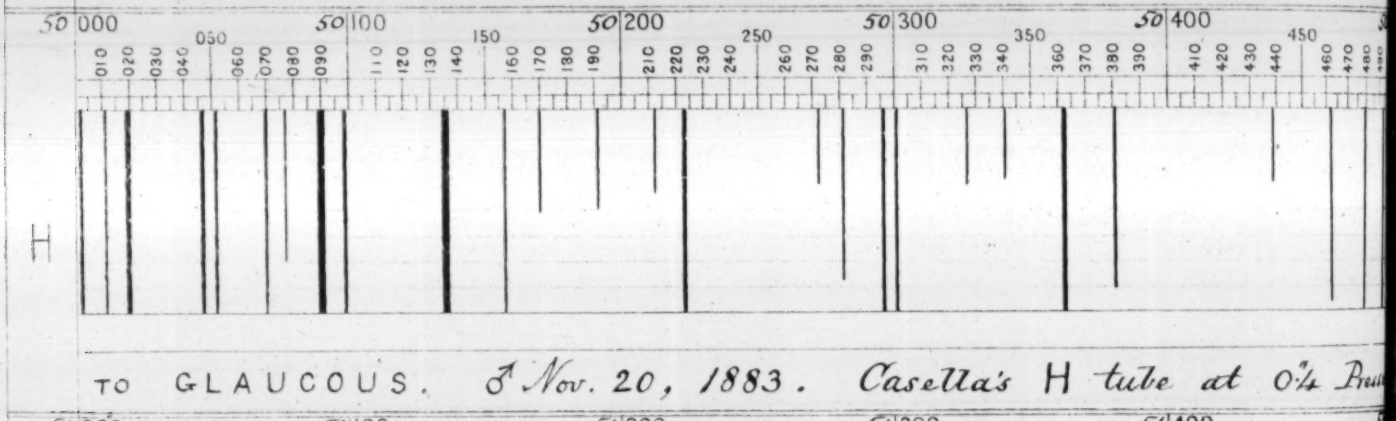
Photo-lith. 1884

T.H. del 2

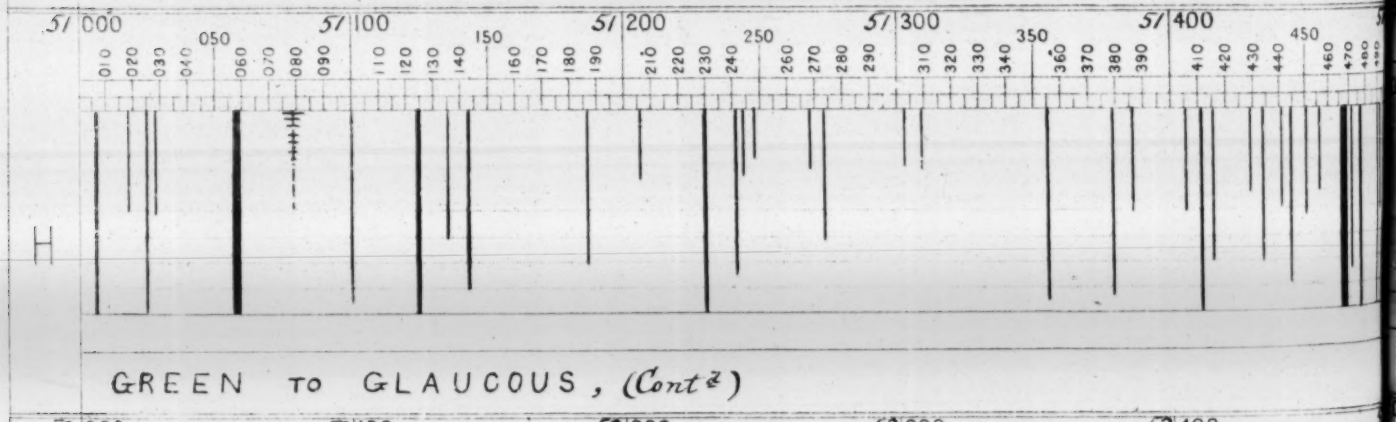
H IN VAC-U



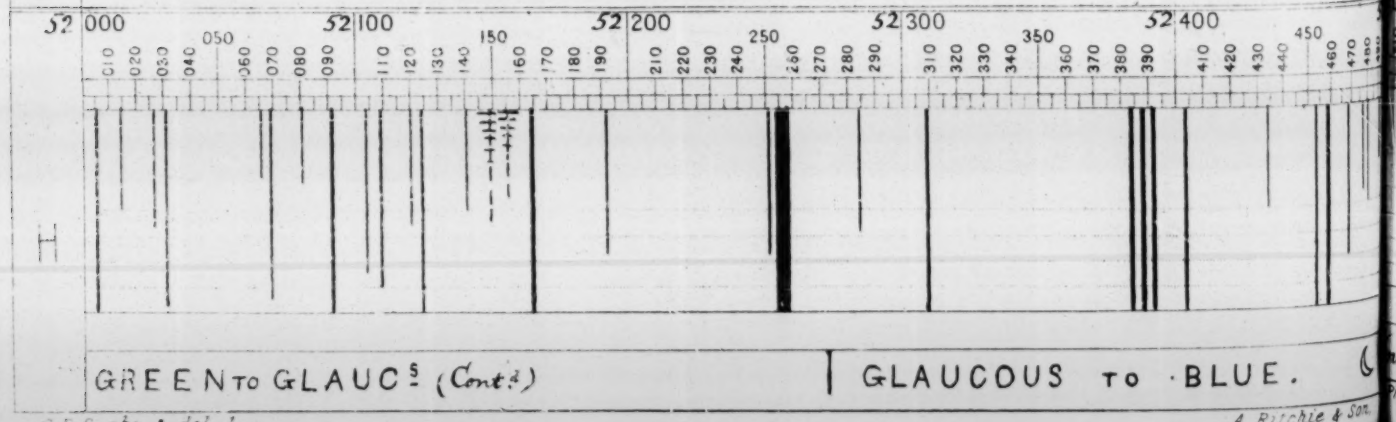
CITRON TO GREEN, (Cont.ᵈ).



TO GLAUCOUS. ♂ Nov. 20, 1883. Casella's H tube at 0.¼ Pressure.



GREEN TO GLAUCOUS, (Cont.ᵈ)

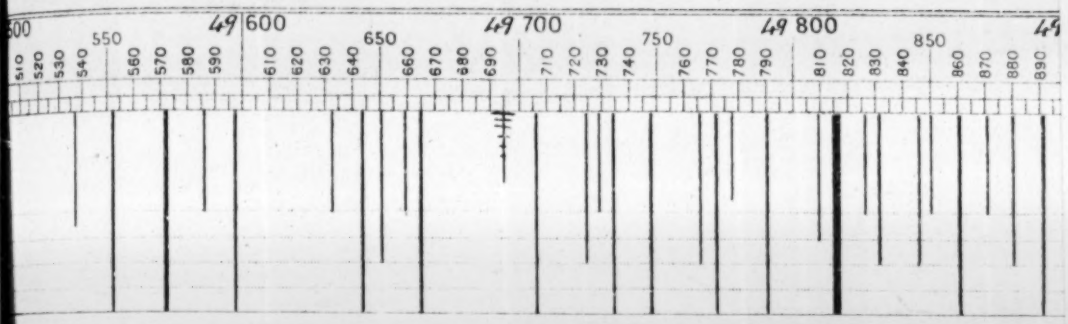


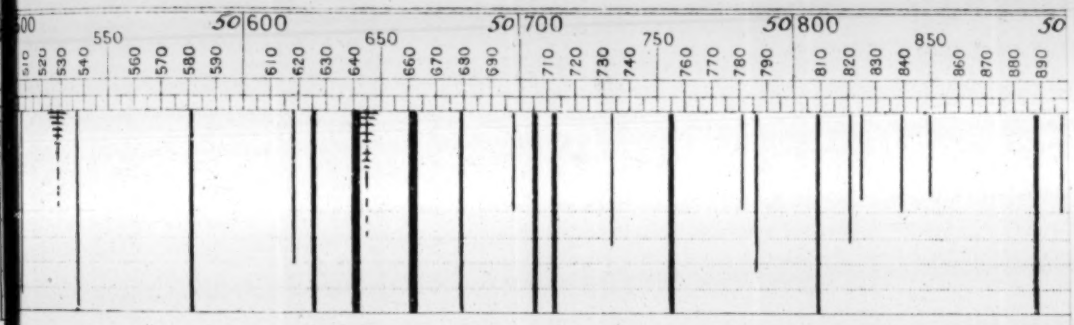
GREEN TO GLAUC.ˢ (Cont.ᵈ) | GLAUCOUS TO BLUE.

C.P.S. obs. & del. 1

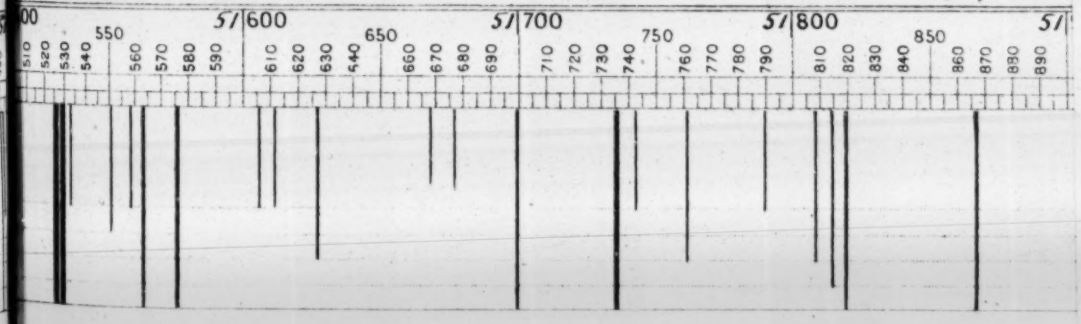
A. Ritchie & Son.

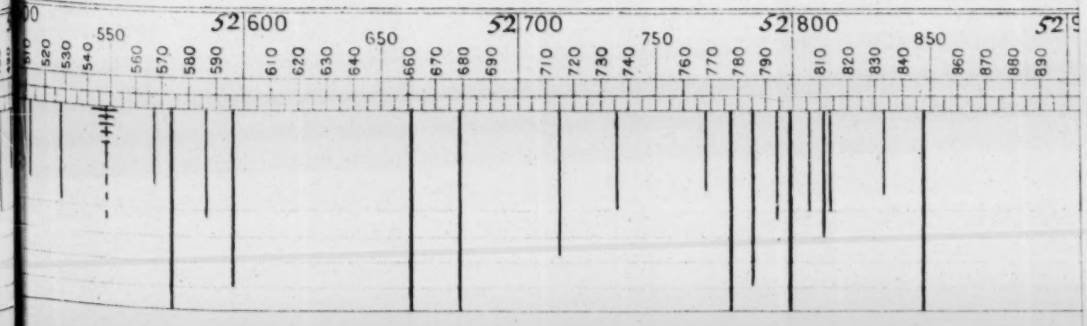
C-UUM - TUBE





Pressure. Prismatic Dispersion = 48° A to H. Mag. power

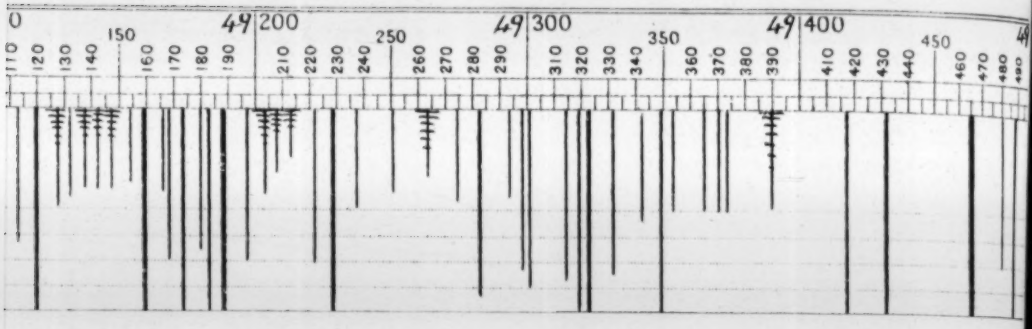




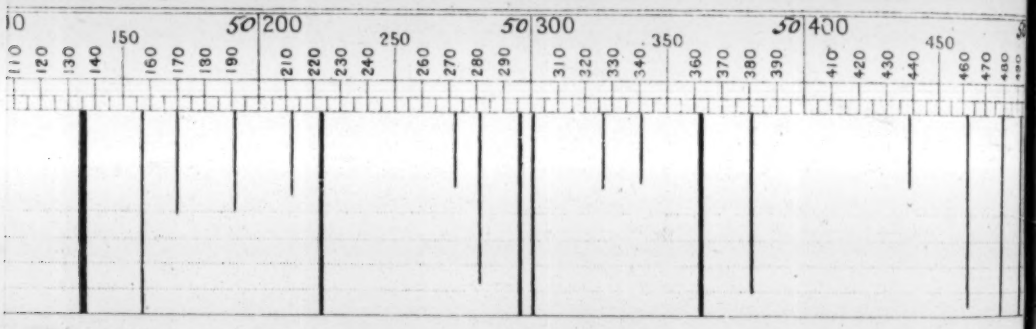
Nov. 5, 1883. Casella's O'4 Pressure tube. Prismatic Dispersion

Photo-Lith 1884.

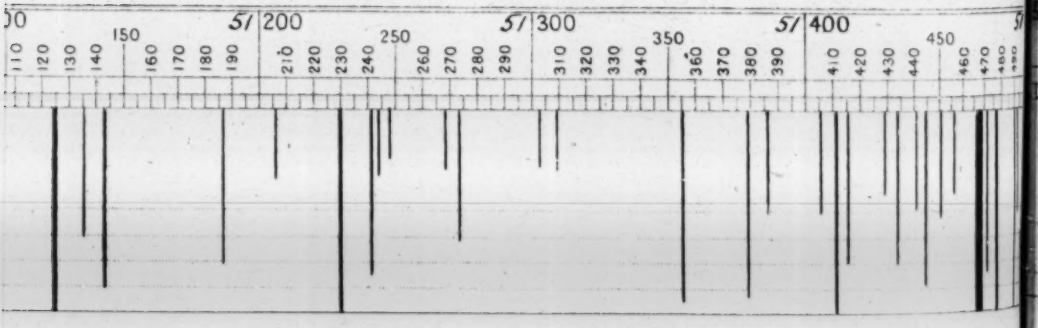
H IN VAC-U



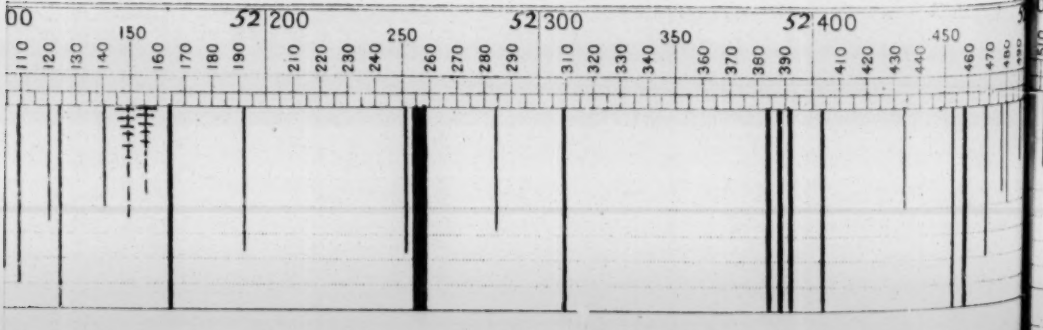
REEN, (Cont^d).



JS. ♂ Nov. 20, 1883. Casella's H tube at 0·4 Pressure.



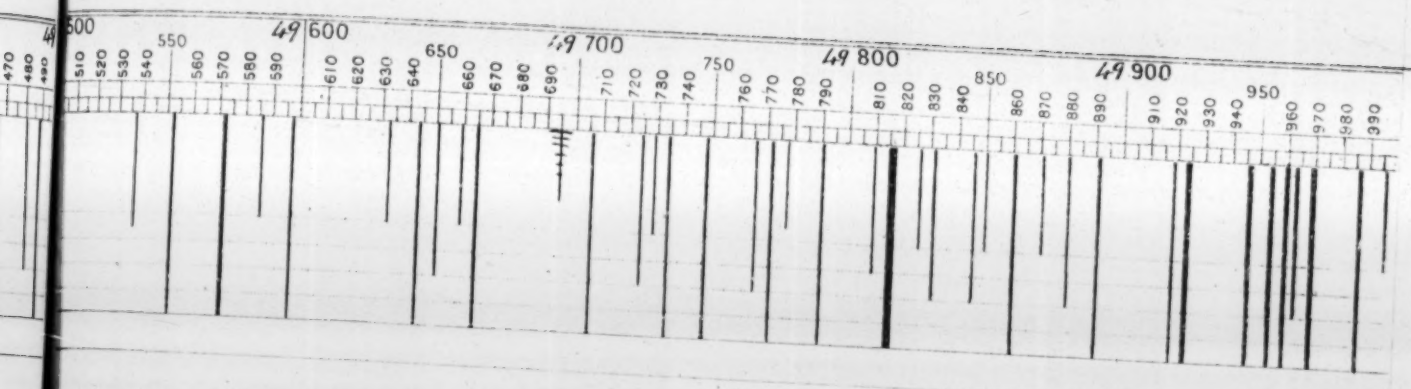
GLAUCOUS, (Cont^d)

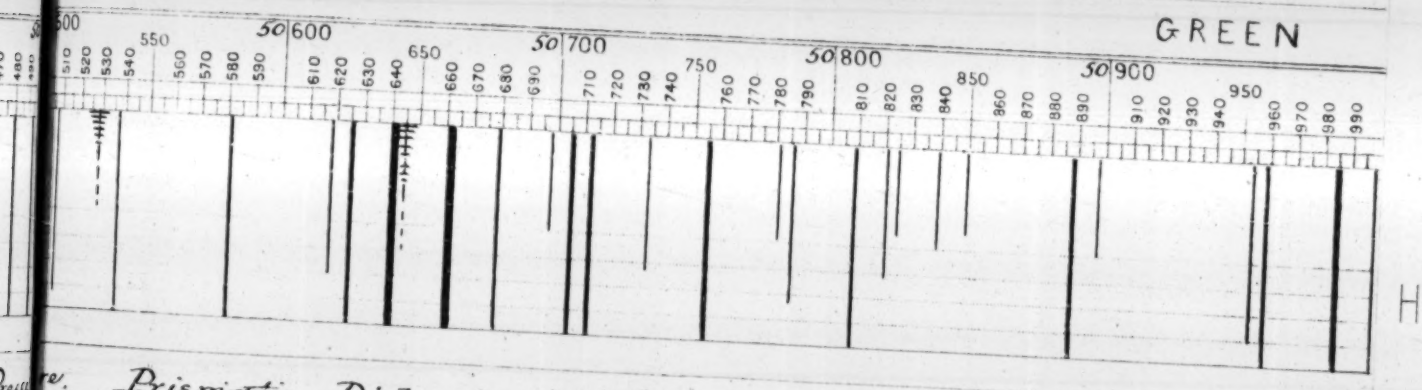


IC^S (Cont^d) | GLAUCOUS TO BLUE. | Nov. 5,

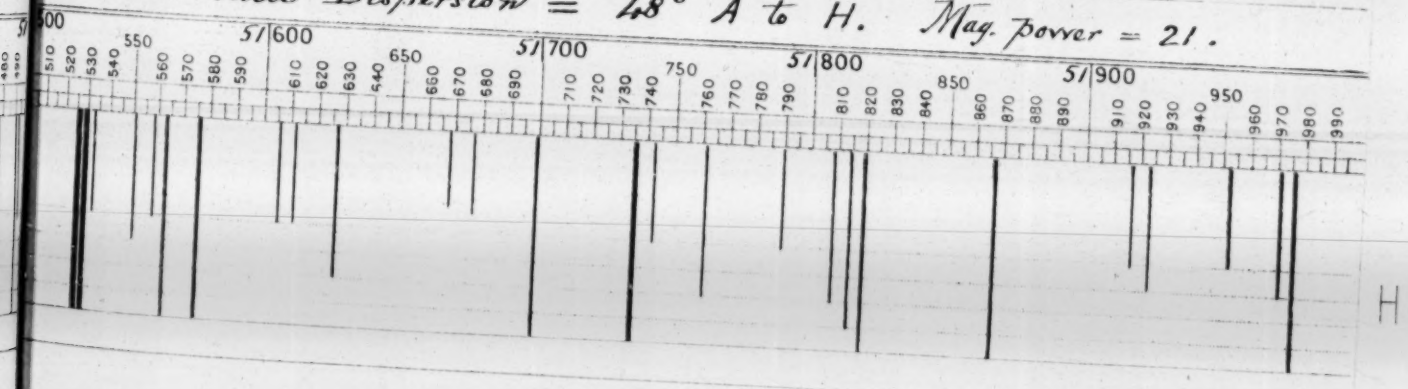
A Ritchie & Son. Photo-lith

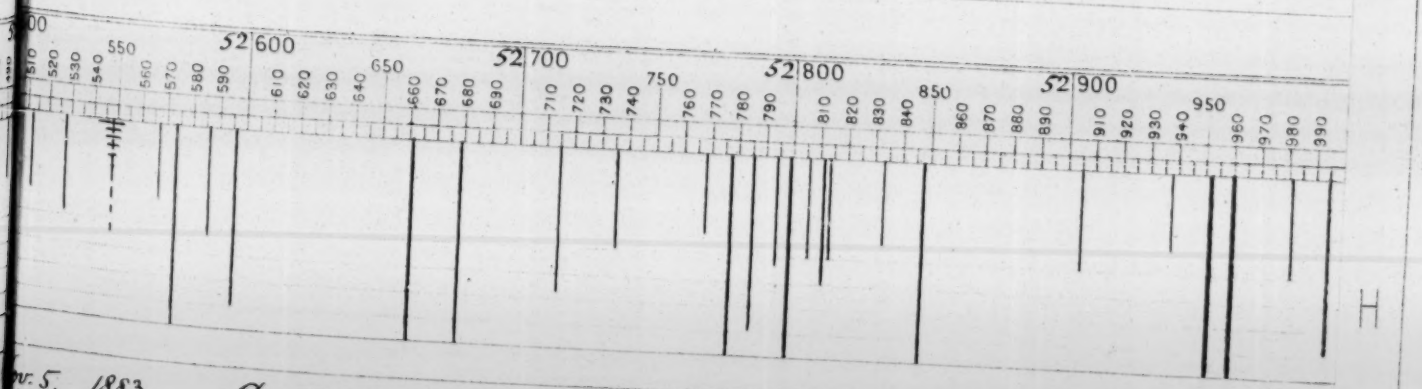
C-UUM-TUBE





re. Prismatic Dispersion = 48° A to H. Mag. power = 21.



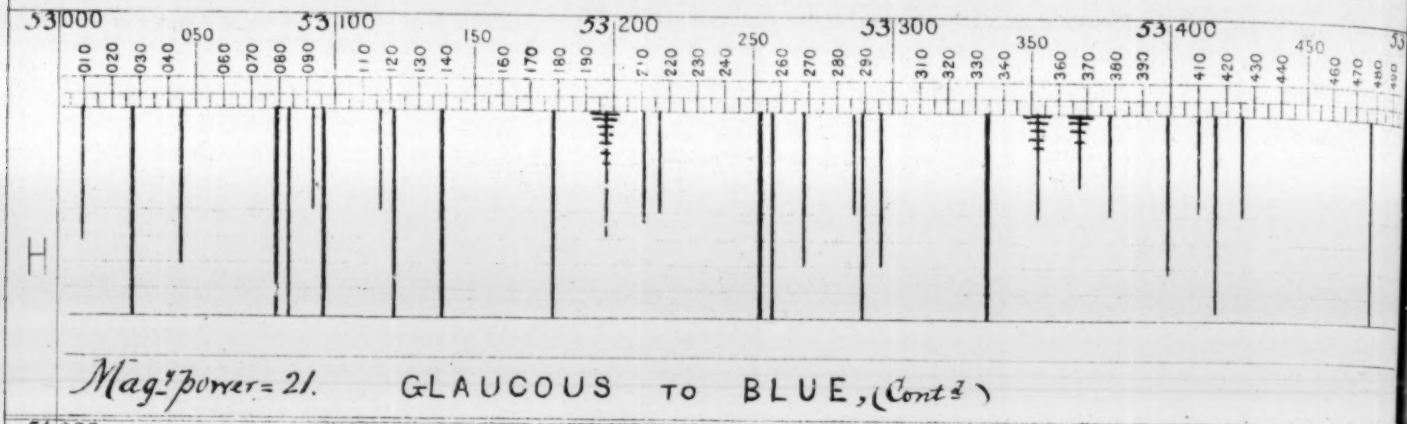


ov. 5, 1883. Casella's 0¼ Pressure tube. Prismatic Dispersion = 48° A to H.

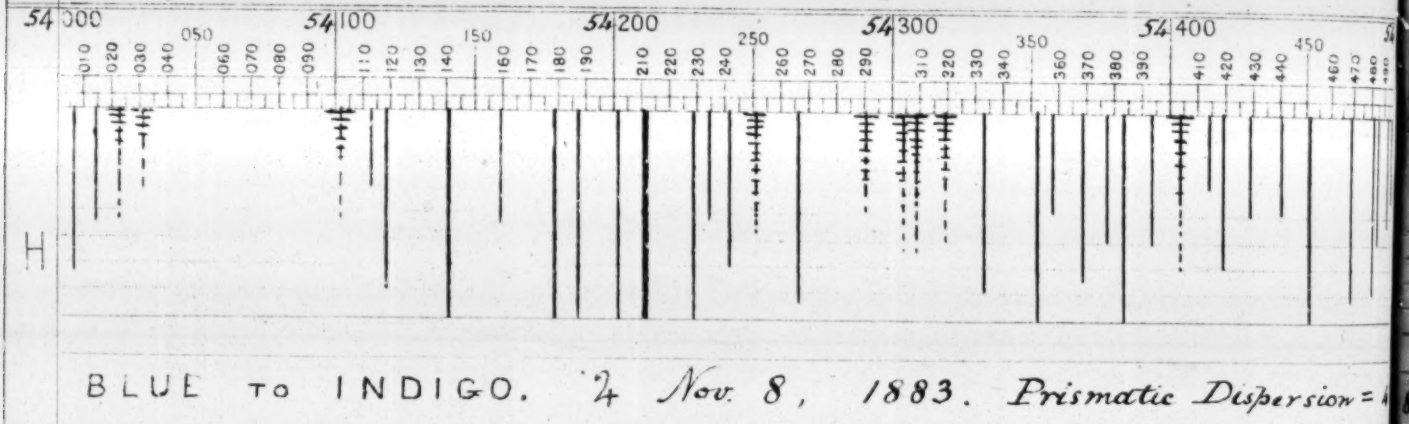
Photo-Lith 1884

T.H. del.

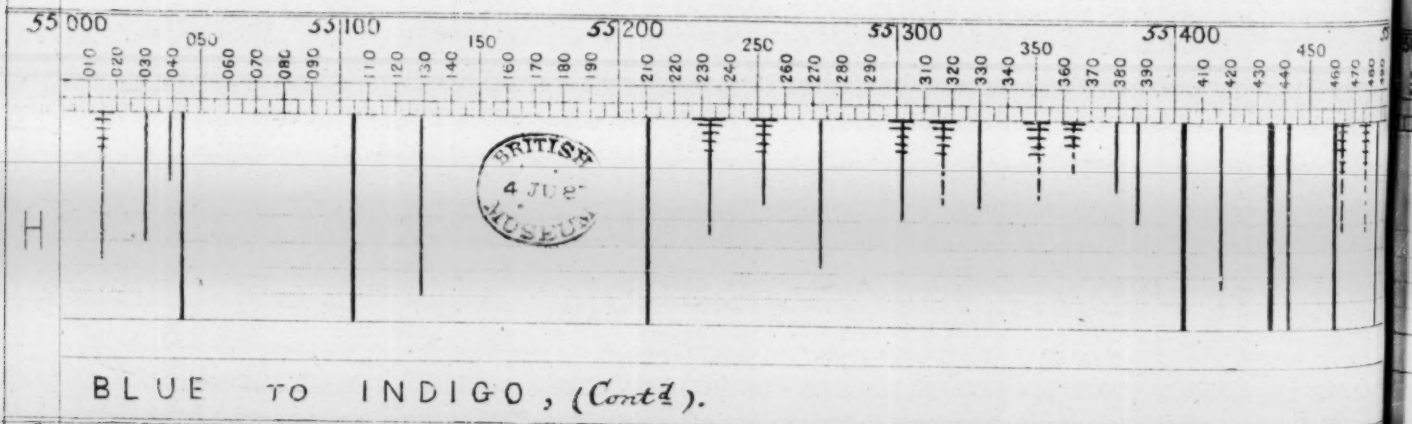
H IN VAC-



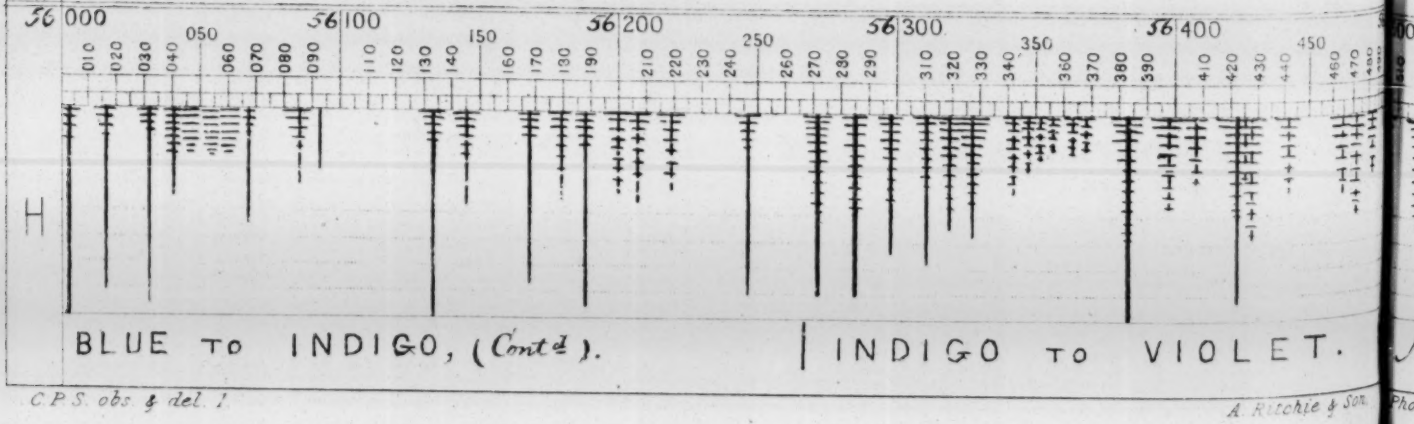
Mag.l power = 21. GLAUCOUS TO BLUE, (Contd)



BLUE TO INDIGO. 4 Nov. 8, 1883. Prismatic Dispersion = 8° A



BLUE TO INDIGO, (Contd).



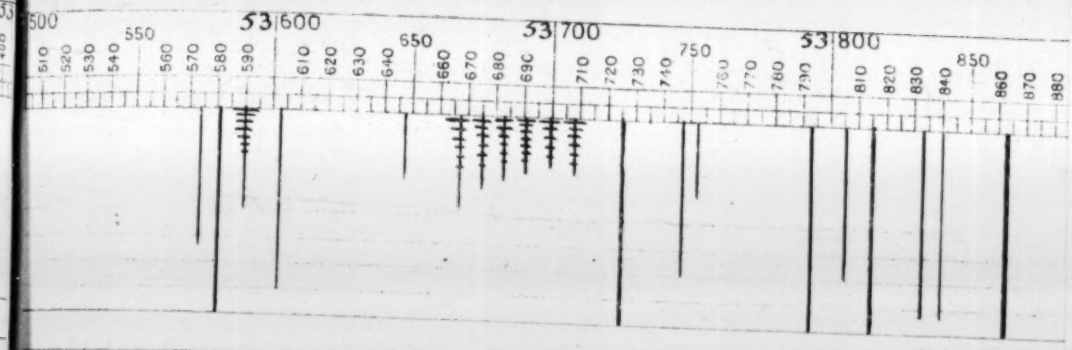
BLUE TO INDIGO, (Contd). | INDIGO TO VIOLET.

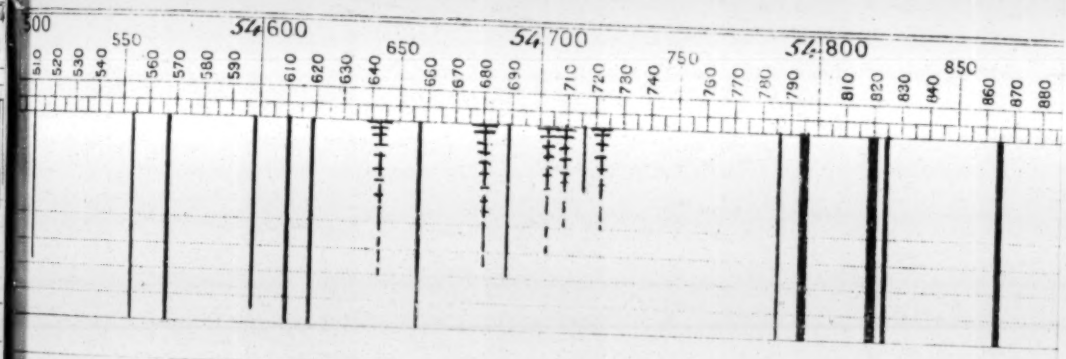
Nov.

C.P.S. obs & del.

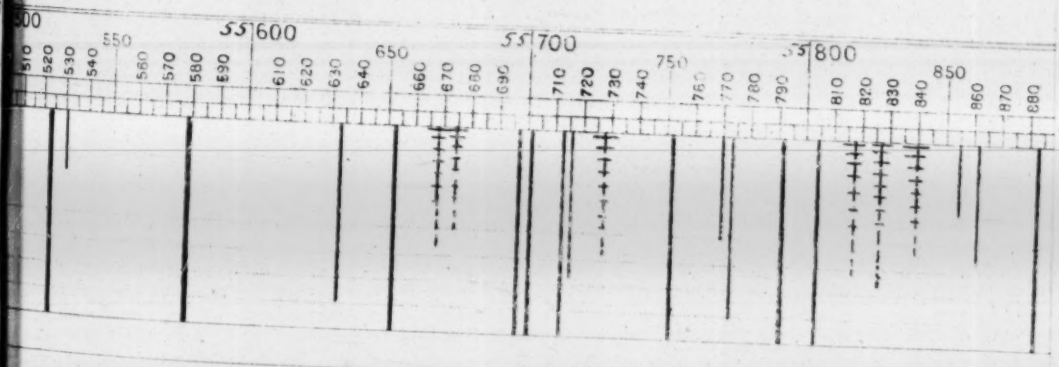
A. Ritchie & Son. Photo-lith

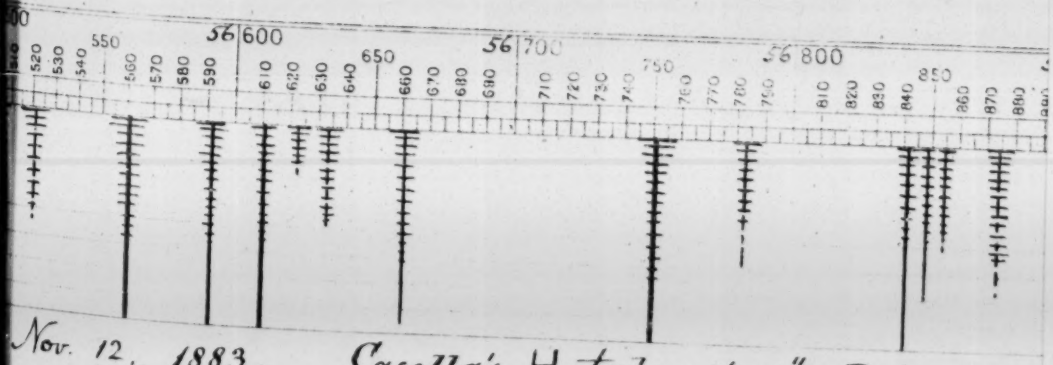
C-UUM-TUBE





8° A to H. Magnifying power = 21

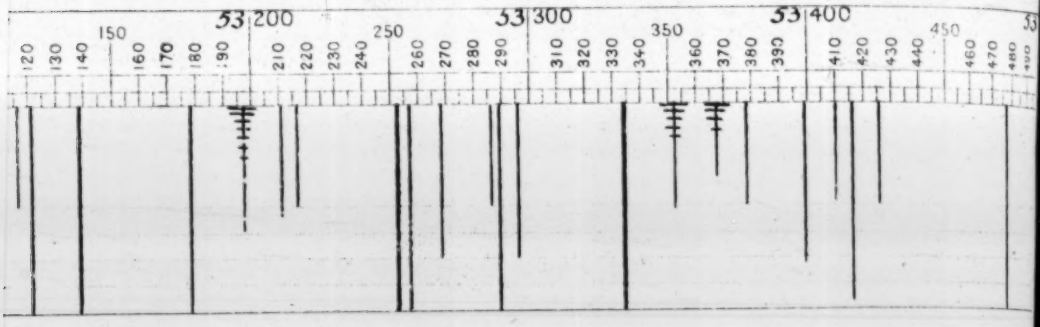




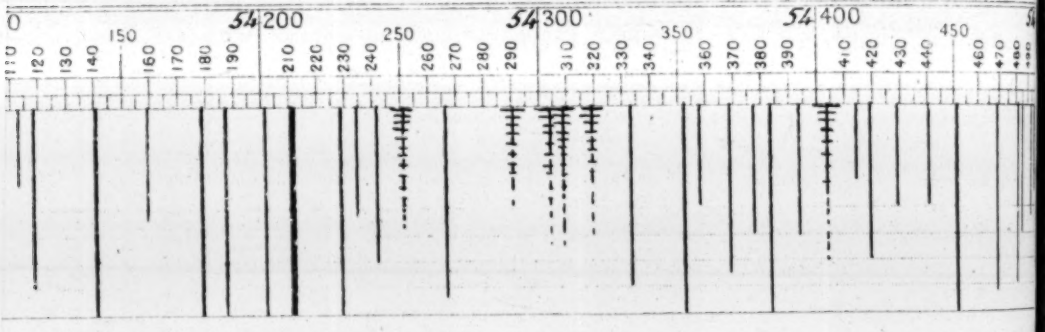
Nov. 12. 1883. Casella's H-tube at 0"4 Pressure. De

Photo-lith 1884

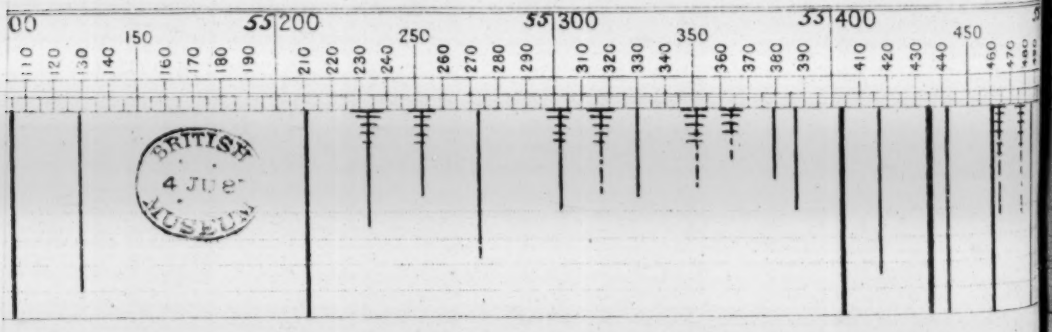
H IN VAC- U



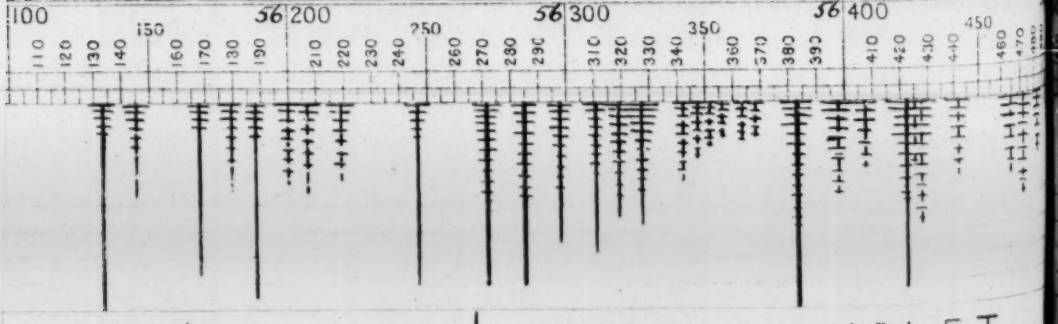
GLAUCOUS TO BLUE, (Cont.d)



NDIGO. 4 Nov. 8, 1883. Prismatic Dispersion = 8° A to



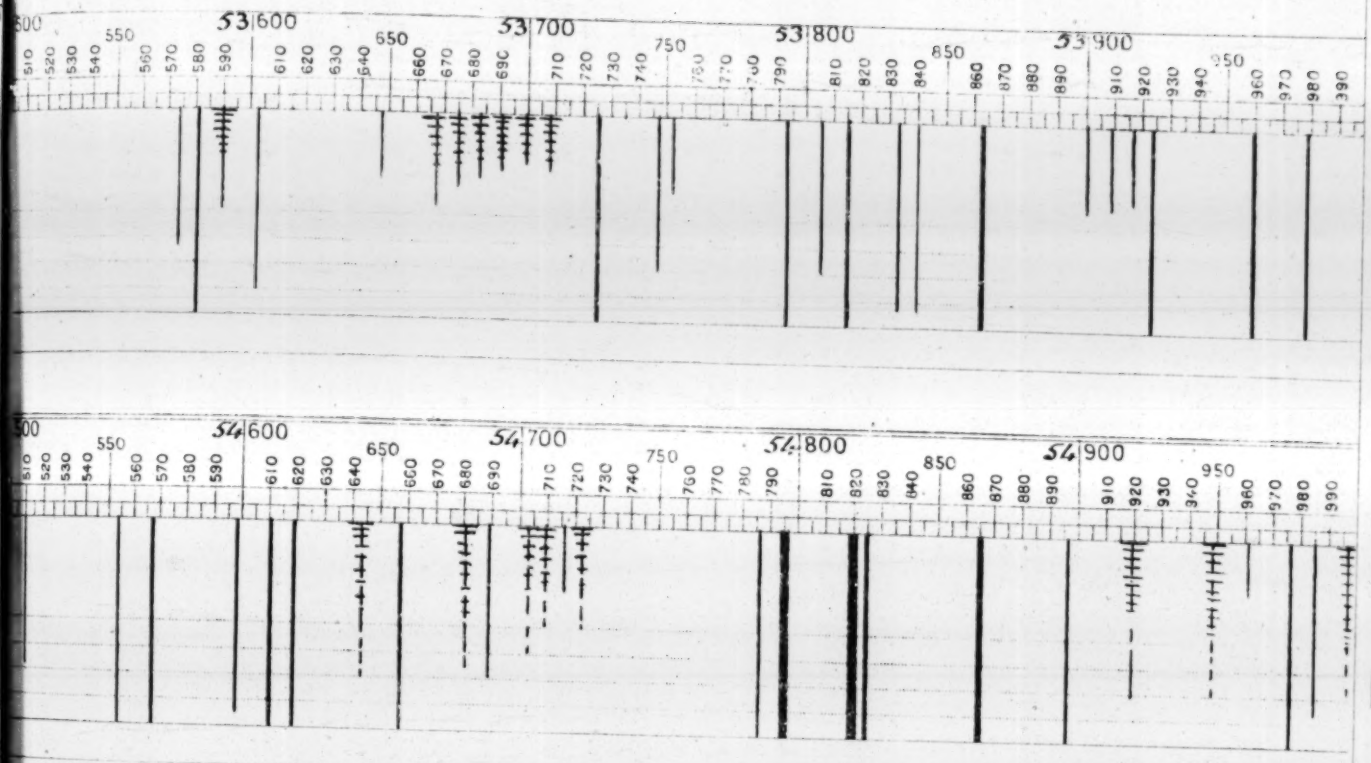
INDIGO, (Cont.d).



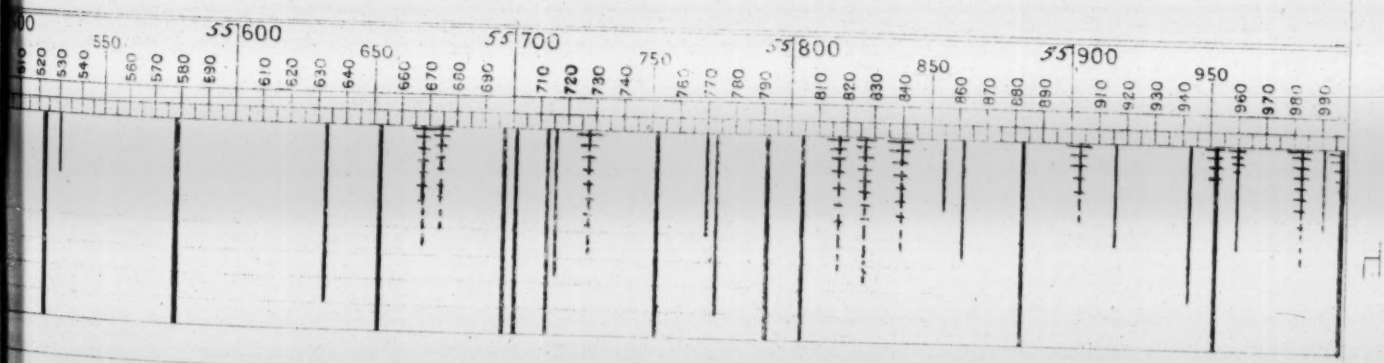
IDIGO, (Cont.d). | INDIGO TO VIOLET. Nov.

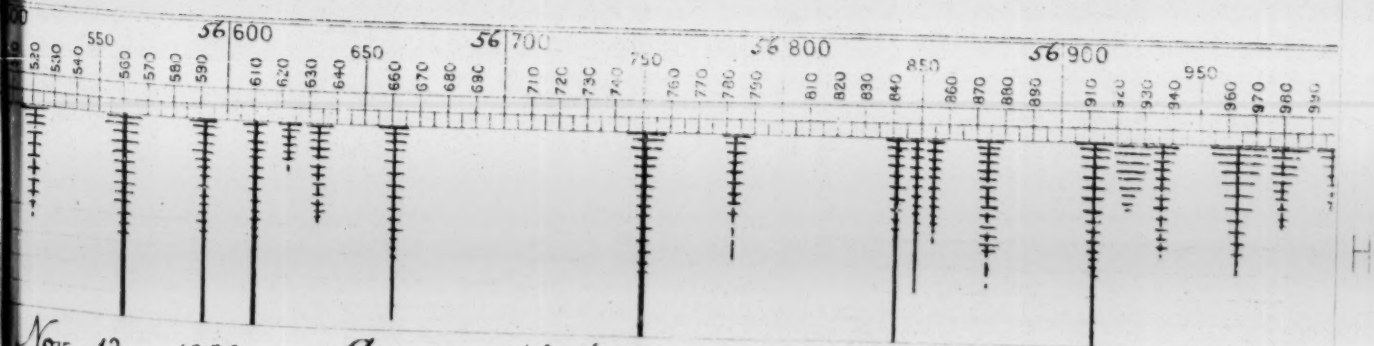
A. Ritchie & Son Photo-Lith

-UUM - TUBE



8° A to H. Magnifying power = 21



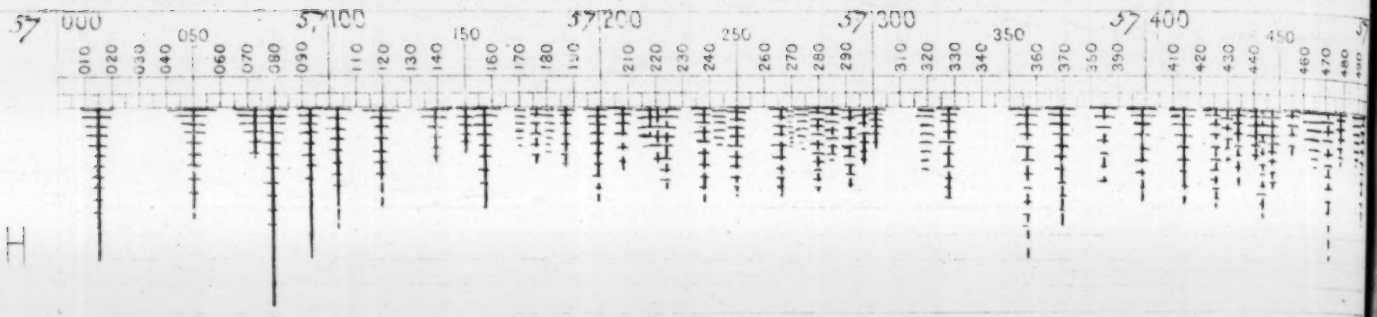


Nov. 12. 1883. Casella's H-tube at 0"4 Pressure. Dispersion = 48°

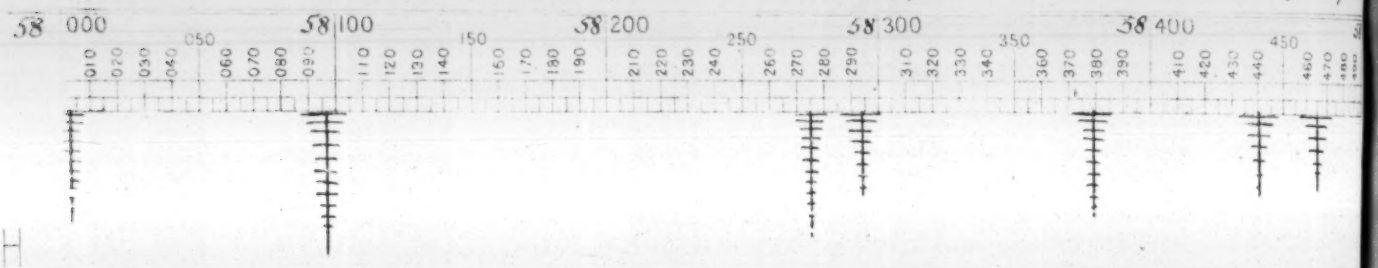
Photo-lith. 1884

T H del 2

H IN VAC·-U



INDIGO TO VIOLET, (Cont^d) Mag^l power = 21. This range pr



VIOLE

INDIGO. TO VIOLET, (Cont^d).

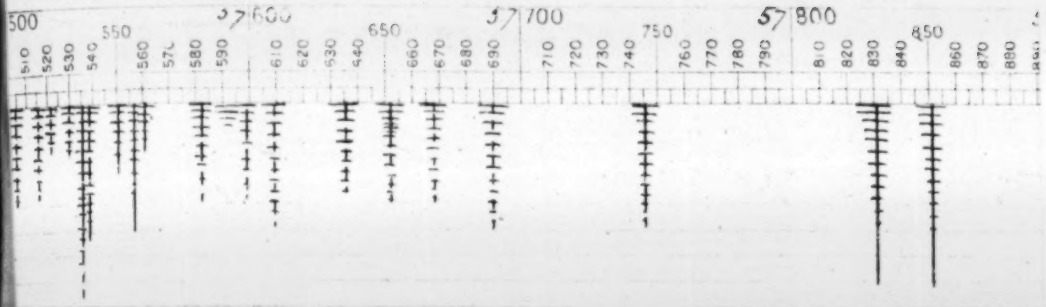
H

H

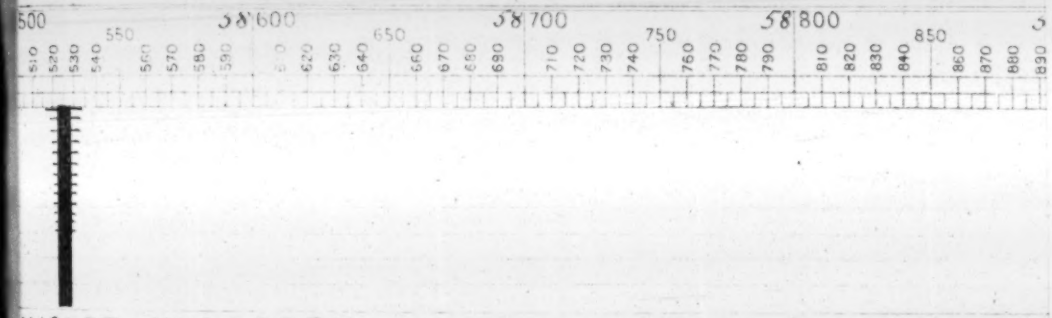
C.P.S. obs & del.

Photo-Lith

-UUM - TUBES



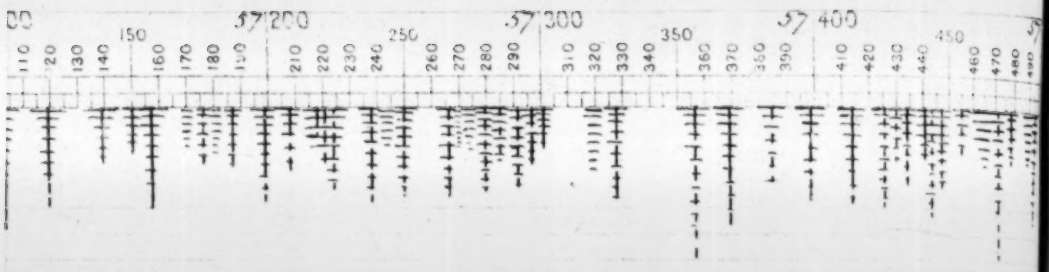
iously taken with 36° Dispersion A to H, but with no bottle



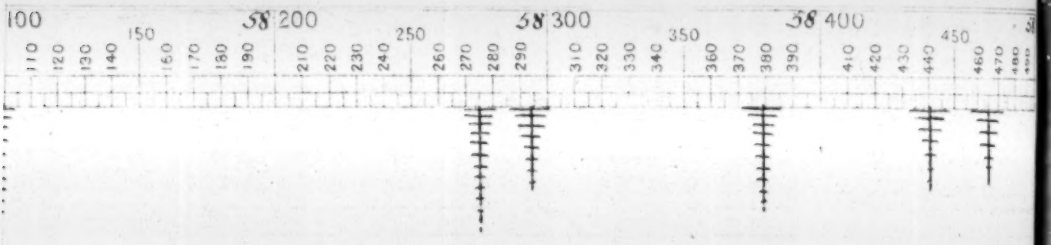
VIOLET HYDROGEN.

Photo-Lith 1884

H IN VAC

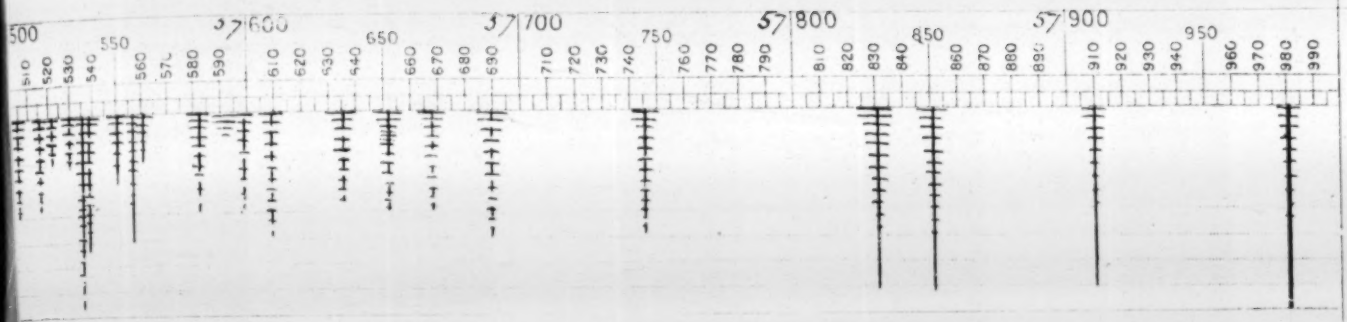


VIOLET, (Cont^d) Mag^r. power = 21. This range pr



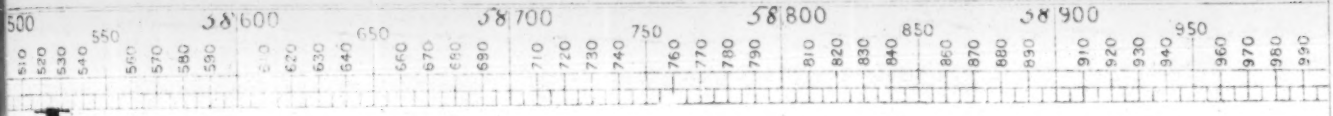
VIOLET, (Cont^d).

-UUM - TUBES



H

iously taken with 36° Dispersion AtoH, but with no better definition



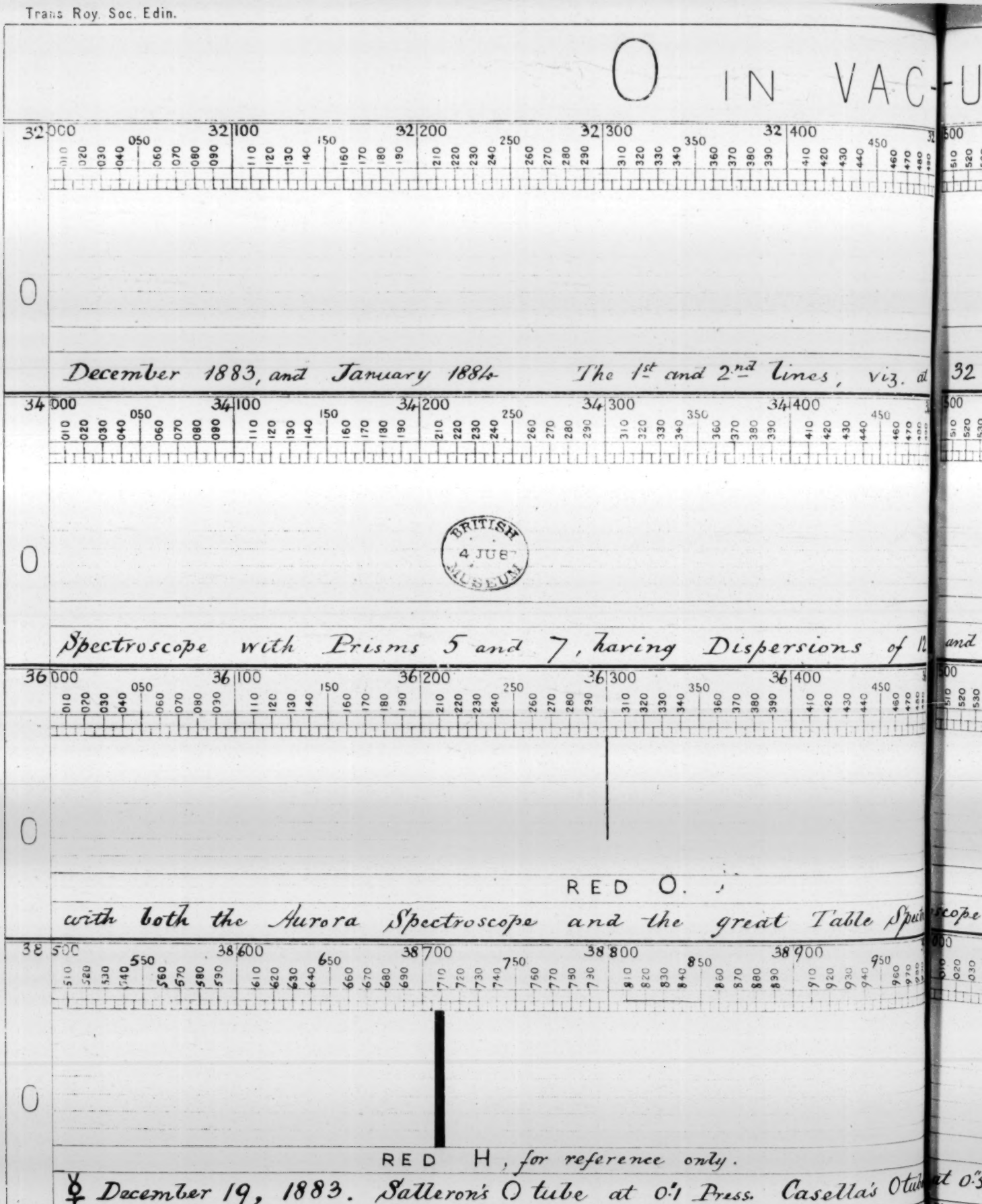


H

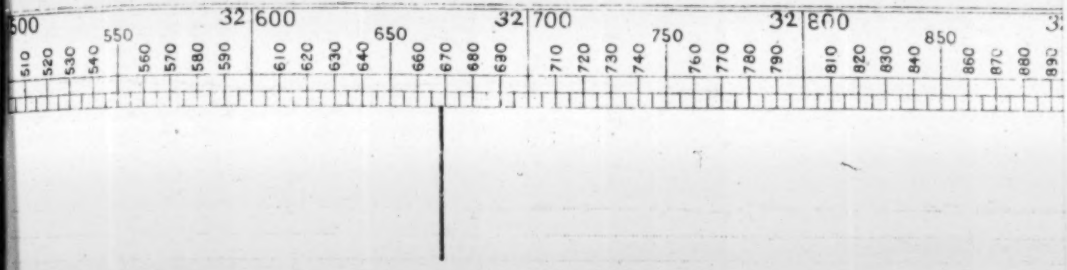
VIOLET HYDROGEN.

H

H

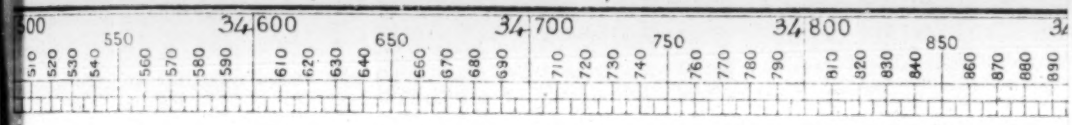

O IN VAC-U
32 000 050 32 100 150 32 200 250 32 300 350 32 400 450
O
December 1883, and January 1884. The 1st and 2nd lines, viz. at
34 000 050 34 100 150 34 200 250 34 300 350 34 400 450
BRITISH 4 JUL MUSEUM
O
Spectroscope with Prisms 5 and 7, having Dispersions of
36 000 050 36 100 150 36 200 250 36 300 350 36 400 450
O
RED O.
with both the Aurora Spectroscope and the great Table Spec
38 500 550 38 600 650 38 700 750 38 800 850 38 900 950
O
RED H, for reference only.
♀ December 19, 1883. Salleron's O tube at 0·1 Press. Casella's O tub
C.P.S. obs. & del. 1.
A. Ritchie & Son.

C-UUM - TUBES



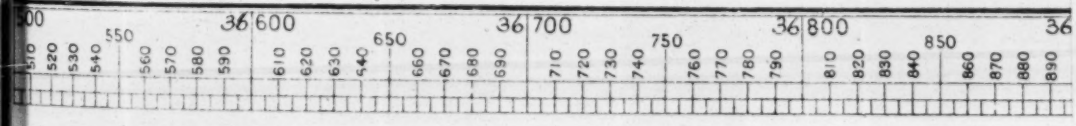
ULTRA RED O

32 670 and 34 925 W.N. Place, were measured in t

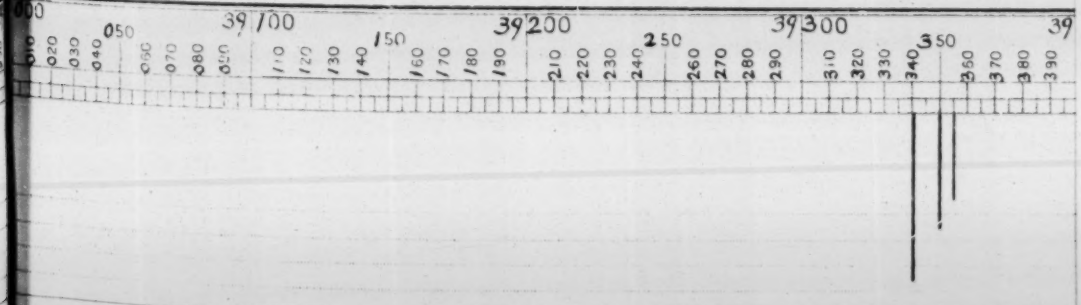


DEE

and 24° respectively, A to H; but the third line



scope with Dispersion = 60° A to H.

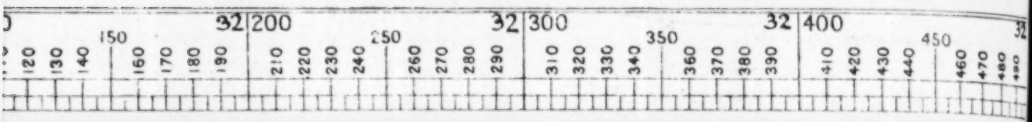


SCARLET

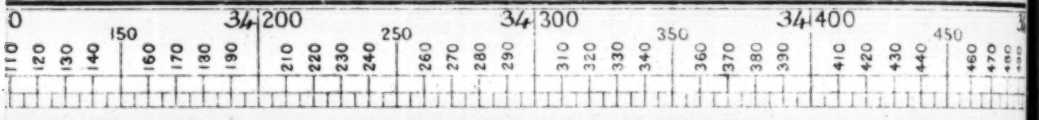
t 0·5 and 2·5 Pressure respectively. Prismatic Disp. = 60° A to H,

Photo-lith. 1884

O IN VAC-U

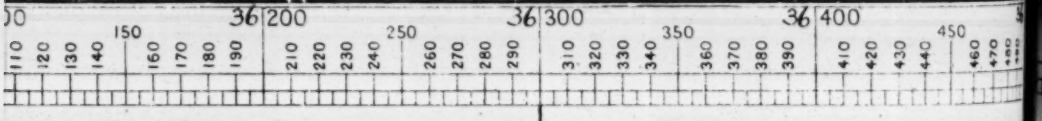


, and January 1884. The 1st and 2nd lines, viz. at



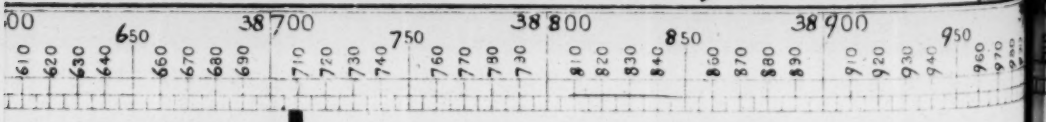
BRITISH
4 JUL
MUSEUM

with Prisms 5 and 7, having Dispersions of 12



RED O.

Aurora Spectroscope and the great Table Spec

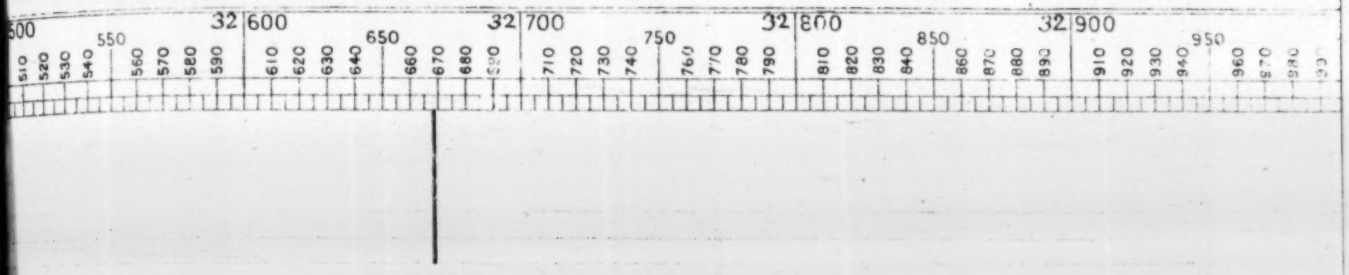


RED H, for reference only.

7, 1883. Salleron's O tube at 0·1 Press. Casella's O tube at 0·5

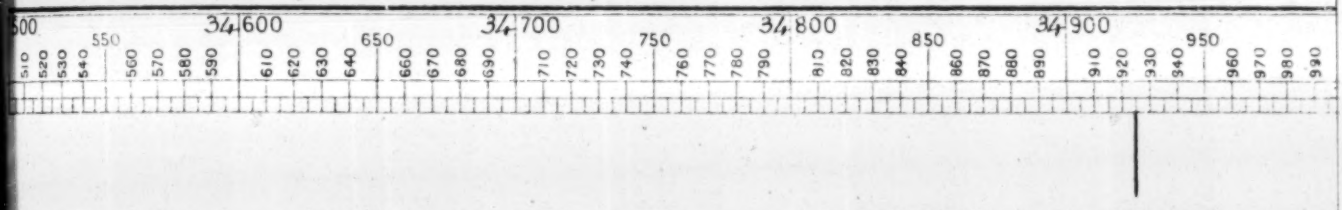
A. Ritchie & Son, Photo-Lith

UUM - TUBES



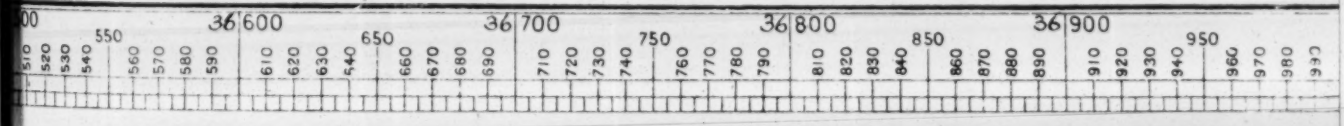
ULTRA RED O

32 670 and 34 925 W.N. Place, were measured in the Aurora

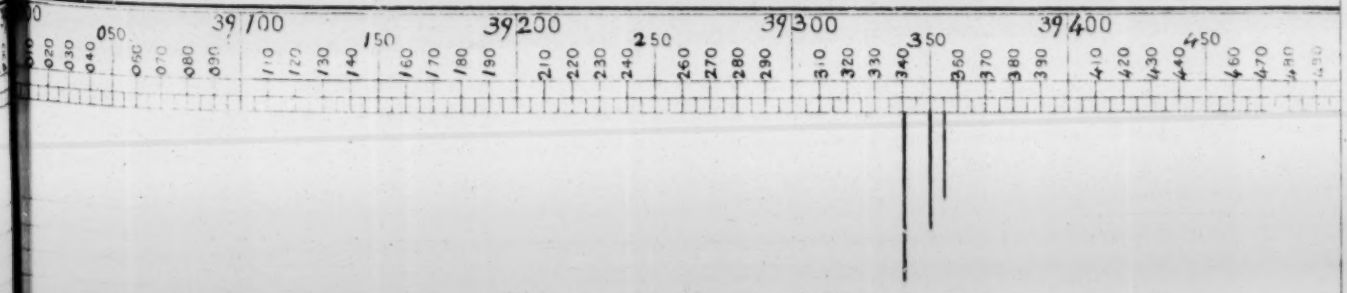


DEEP RED O

and 24° respectively, A to H; but the third line at 36 300 W.N



cope with Dispersion = 60° A to H.



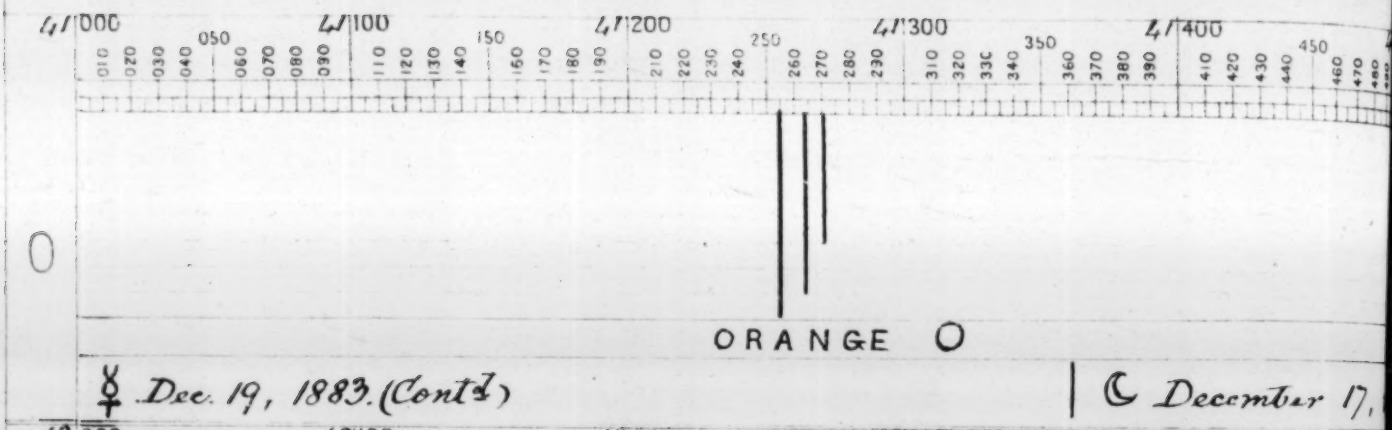
SCARLET O.

at 0·5 and 2·5 Pressure respectively. Prismatic Disp. = 60° A to H, Magfp = 21.

Photo-Lith 1884

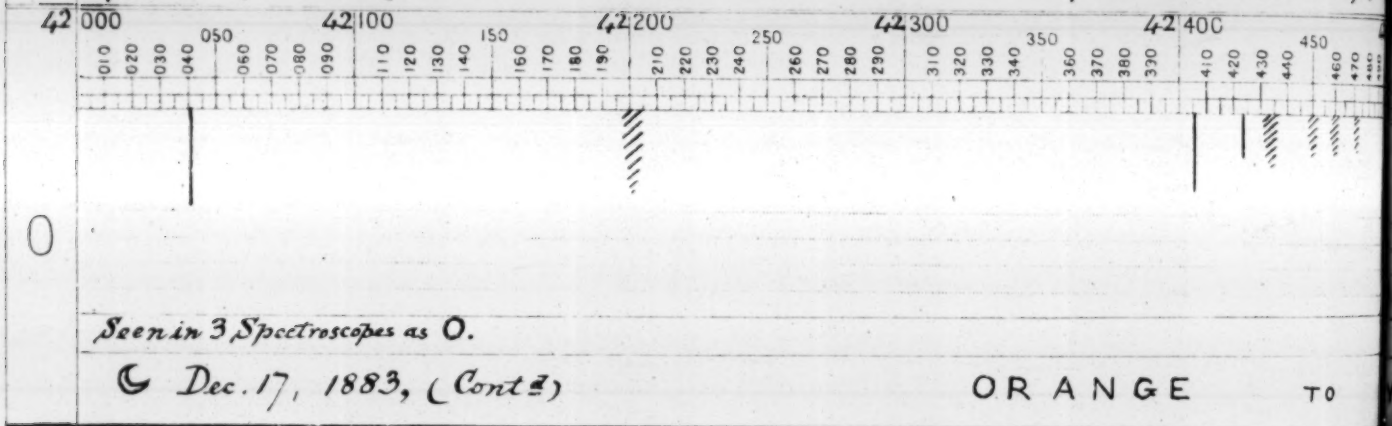
T H del 2

O IN VAC



☿ Dec. 19, 1883. (Cont.)

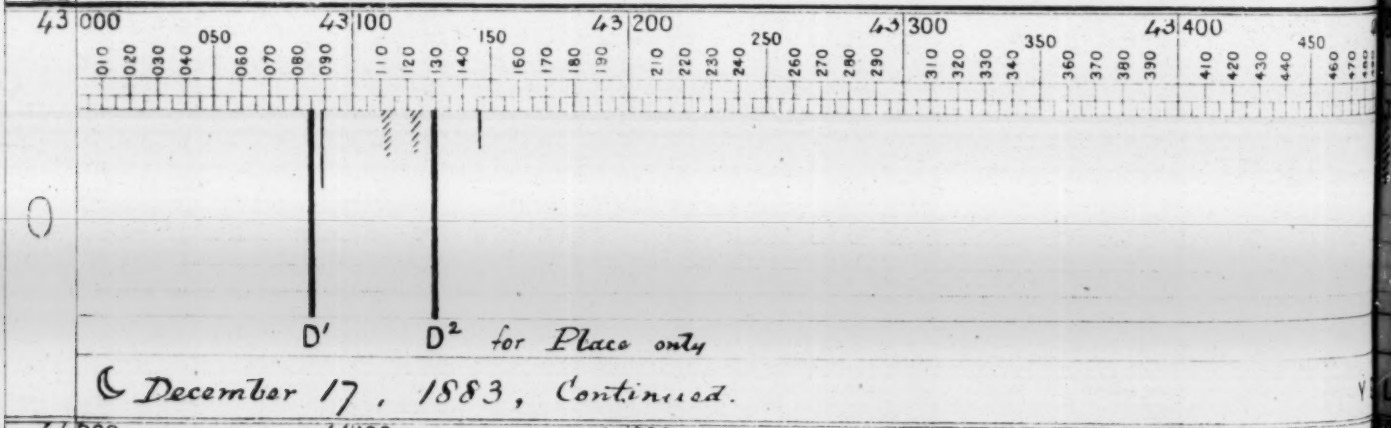
☾ December 17, 1883.



Seen in 3 Spectroscopes as O.

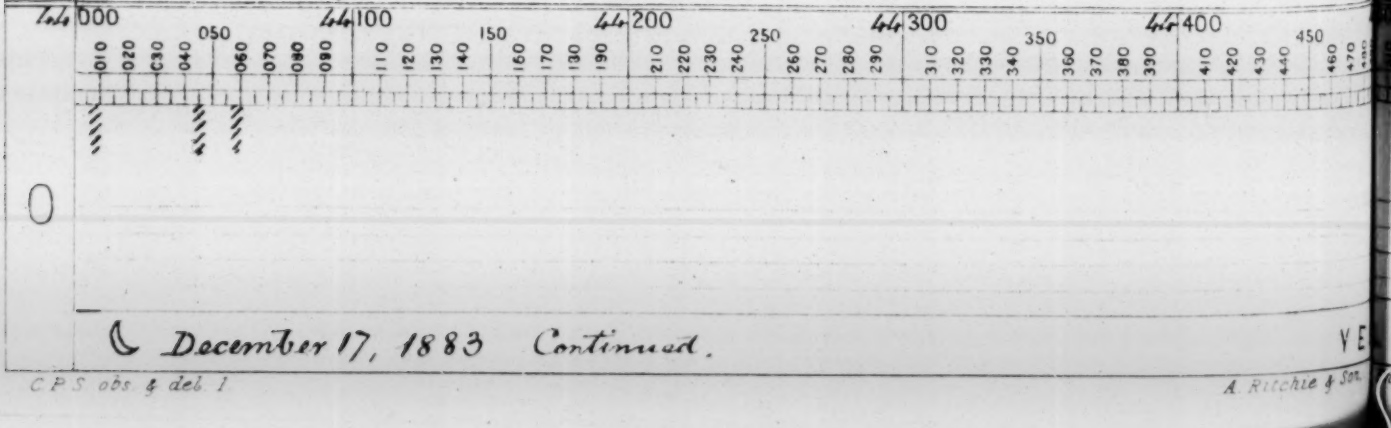
☾ Dec. 17, 1883, (Cont.)

ORANGE TO YEL



☾ December 17, 1883, Continued.

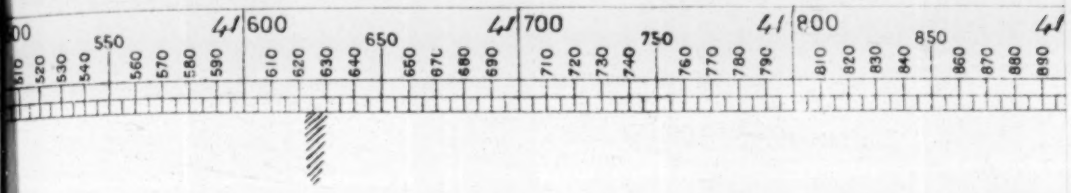
YELLO



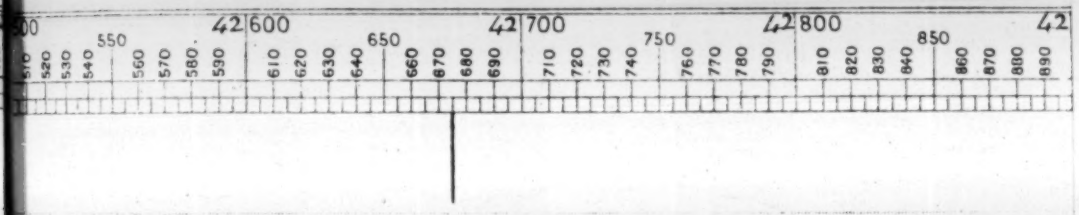
☾ December 17, 1883 Continued.

YELOW

C UUM - TUBES

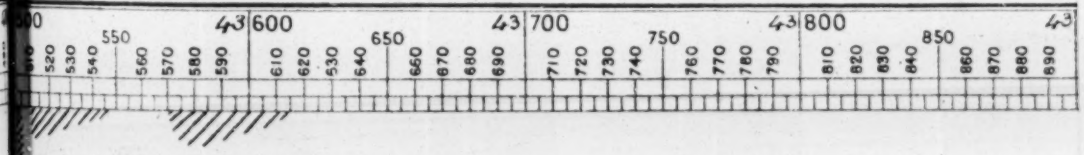


7, 1883. Casella's O tubes at 0"5 and 2"5 Press. Magl powe

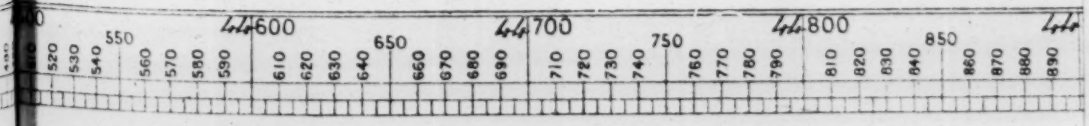


Seen in 3 Spectroscopes as O.

YELLOW.



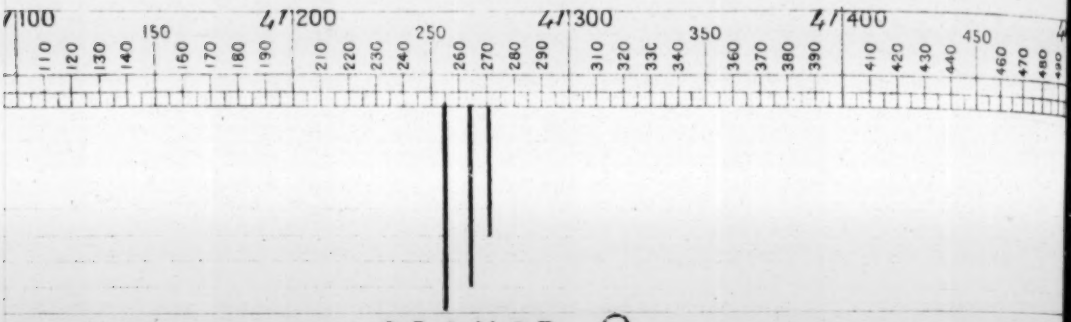
YELLOW COLOUR.



YELLOW.

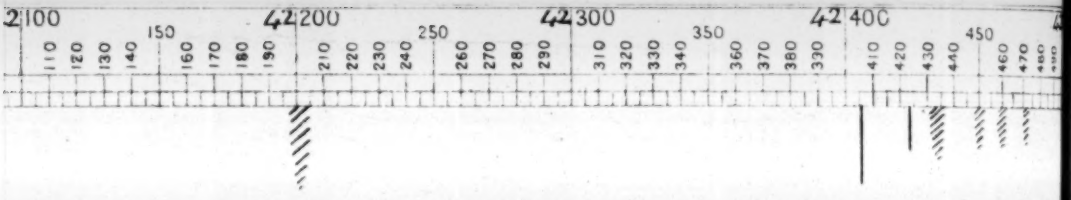
Photo-lith 1884

O IN VAC-U



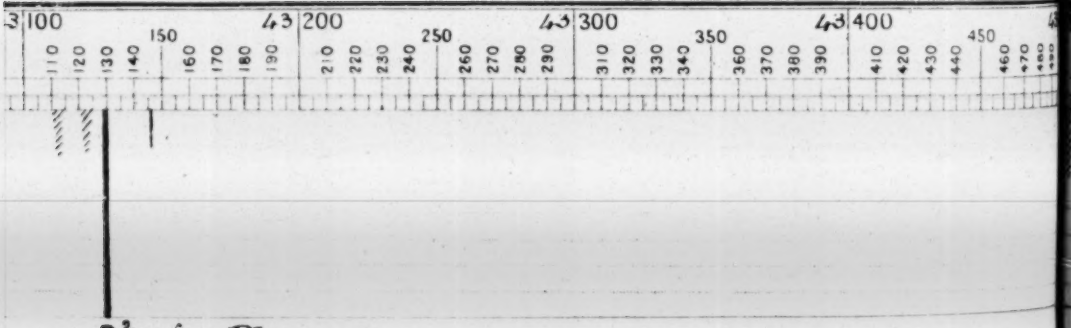
ORANGE O

83. (Cont'd) | December 17, 1883.



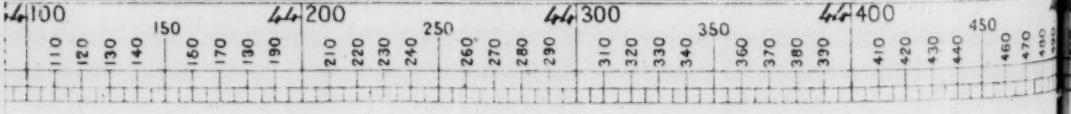
scopes as O.

1883, (Cont'd) ORANGE TO YEL



D^2 for Place only

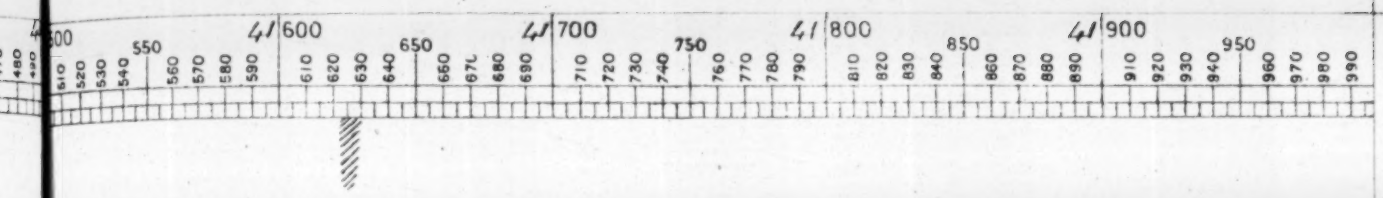
17, 1883, Continued. YELLO



17, 1883 Continued. YELLOW

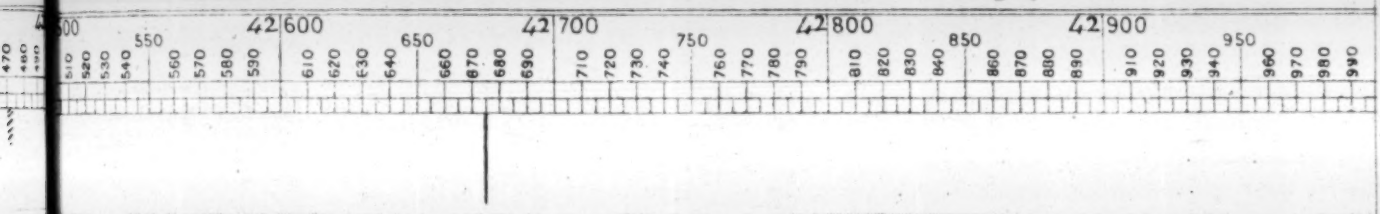
A. Ritchie & Son. Photo-Li

C-UUM - TUBES



0

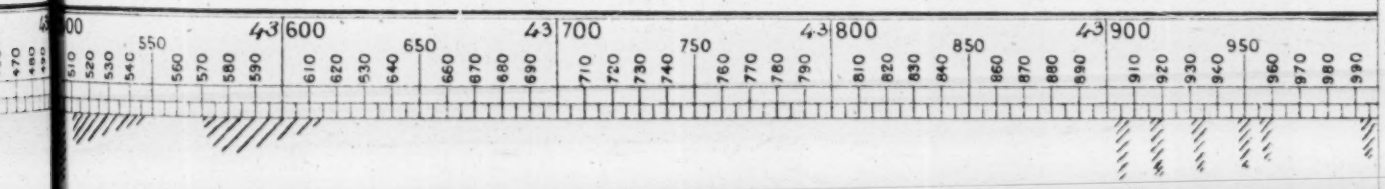
7, 83. Casella's O tubes at 0"5 and 2"5 Press. Magl power = 21.



0

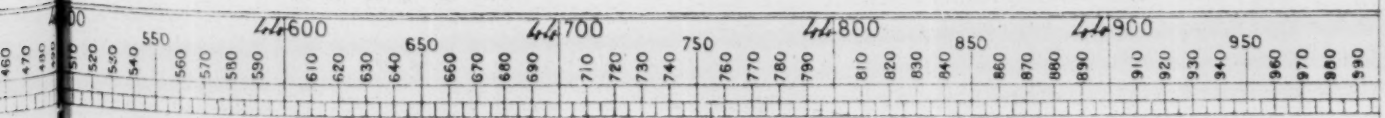
Seen in 3 Spectroscopes as O.

ELLOW.



0

YELLOW COLOUR.



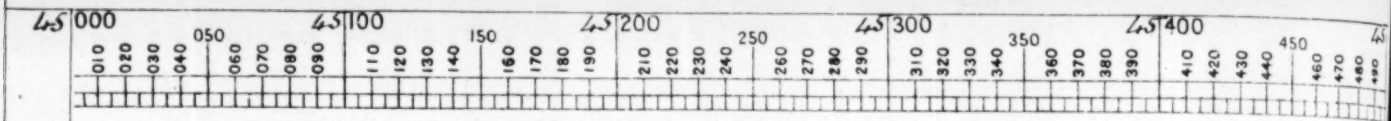
0

YELLOW.

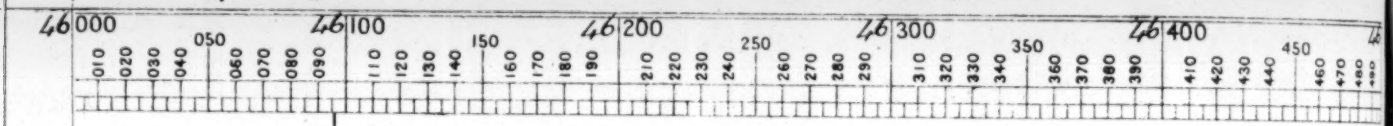
& Son. Photo-Lith 1884

T H del

O IN VAC-U



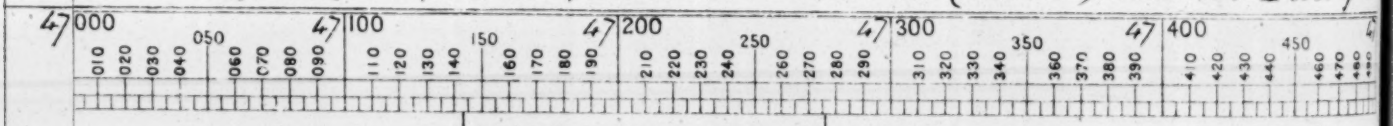
☾ Dec. 17, 1883 (Cont^{d}). YELLOW TO CITRON.



BRITISH
4 JUE
MUSEUM

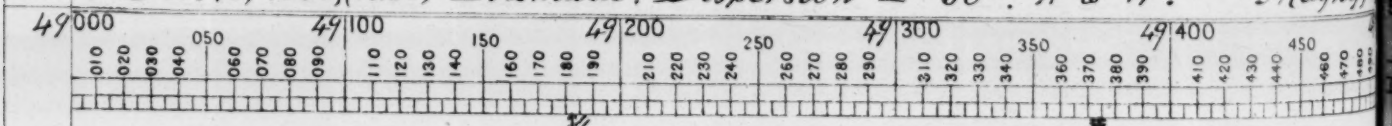
CITRON COLOUR.

☌ Dec. 18, 1883, (Cont^{d}). and Salleron's O tube at (believed) 0·1 Press. Full of CO



CITRON — GREEN COLO

☌ Dec. 18, 1883, (Cont^{d}) Prismatic. Dispersion = 60°. A to H. Magnify



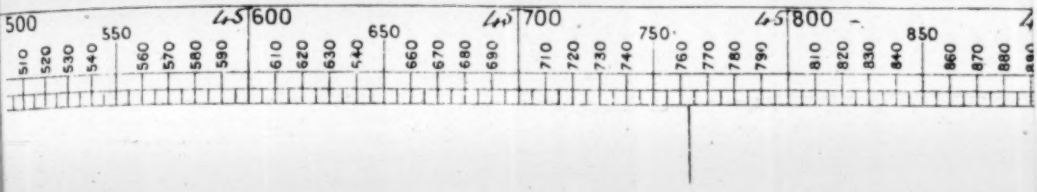
C.H's Green Giant, for place only.

♄ January 12, 1884. Casella's 0·5 Press. O tube. Prismatic Disp

C.P.S. obs & del. 1

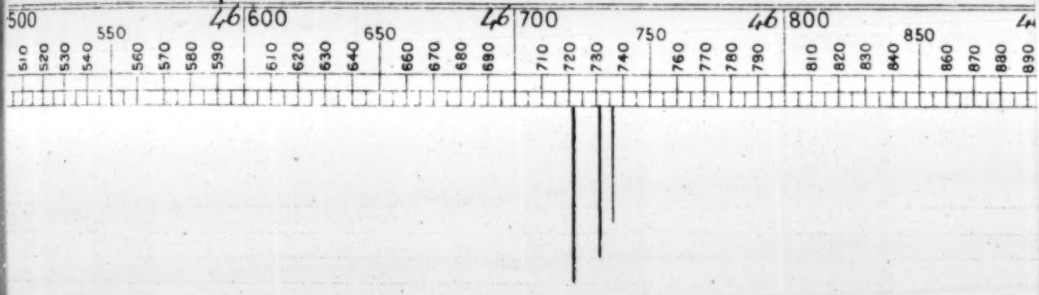
A. Ritchie & Son.

C-UUM - TUBES

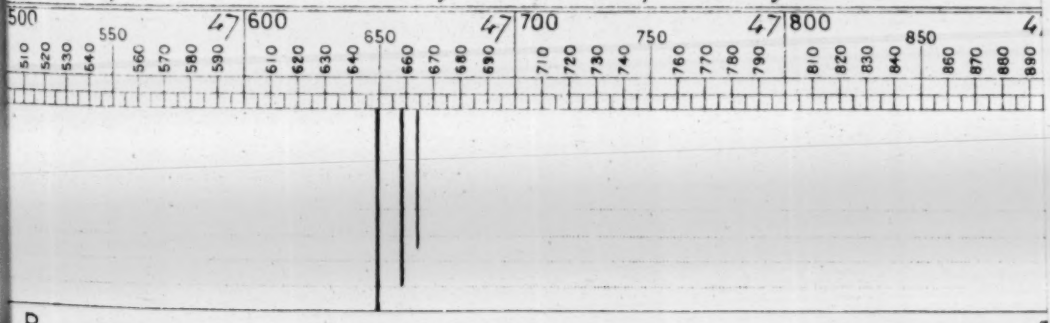


Testified for O by 3 Spectroscopes.

♂ December 18, 1883. Casella's O tubes at

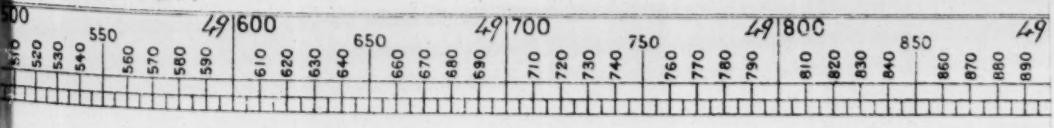


and H impurities, but showing the O triples brighter than Casel



R.

Power = 21.

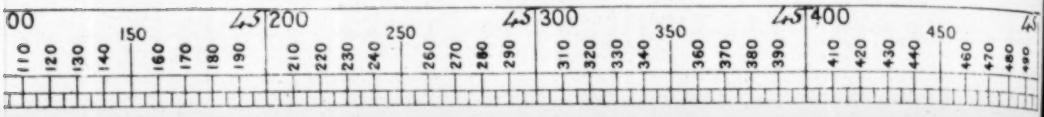


REEN COLOUR.

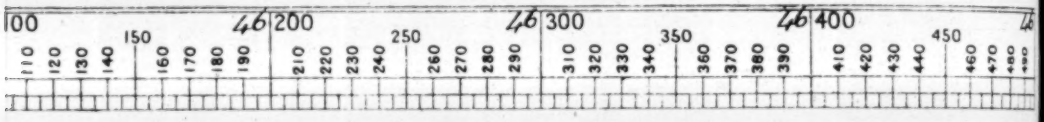
sion = 48°. Magnifying power = 21.

Photo-lith 1884

O IN VAC-U



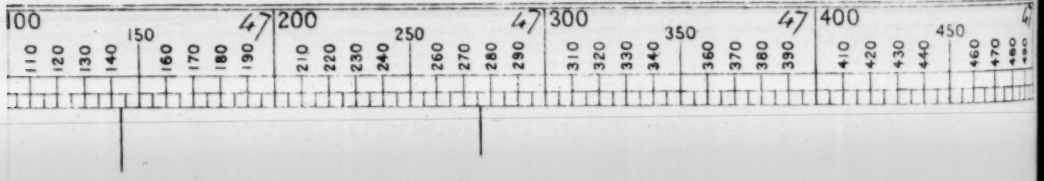
(2). YELLOW TO CITRON.



BRITISH
4 JUS
MUSEUM

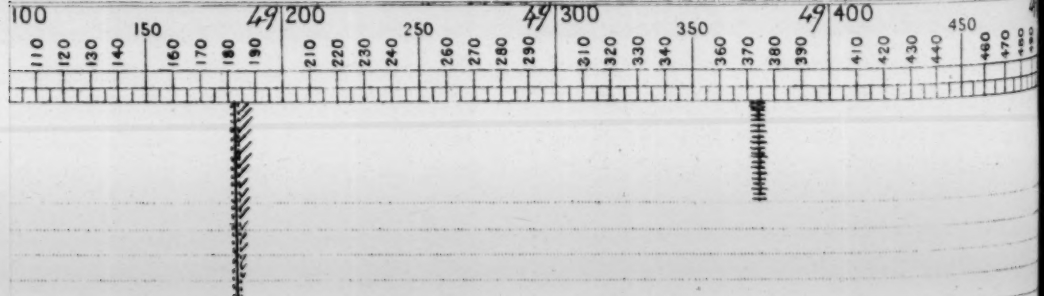
CITRON COLOUR.

(Cont^d). and Salleron's O tube at (believed) 0.1 Press. Full of CO



CITRON — GREEN COLO

(Cont^d) Prismatic. Dispersion = 60°. A to H. Magnifyi

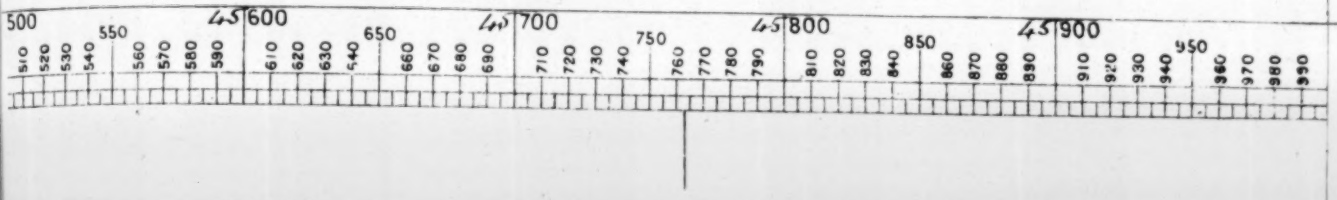


C.H's Green Giant, for place only.

'2, 1884. Casella's 0.5 Press. O tube. Prismatic Disp

A. Ritchie & Son.

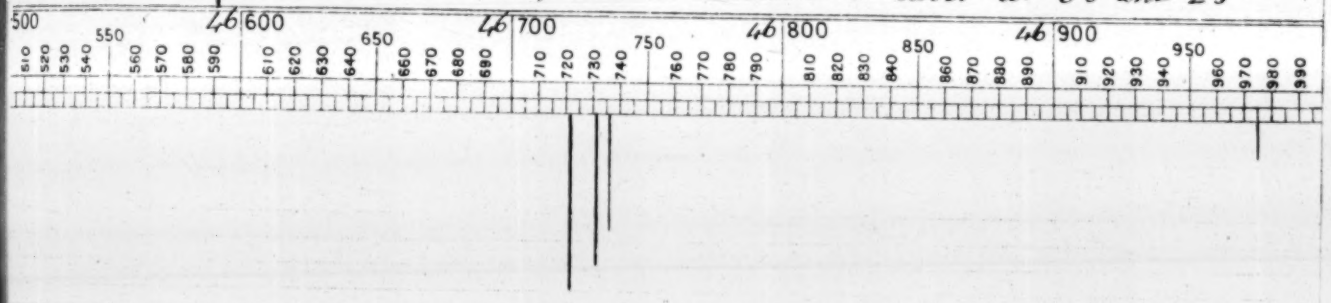
C-UUM - TUBES



0

Testified for O by 3 Spectroscopes.

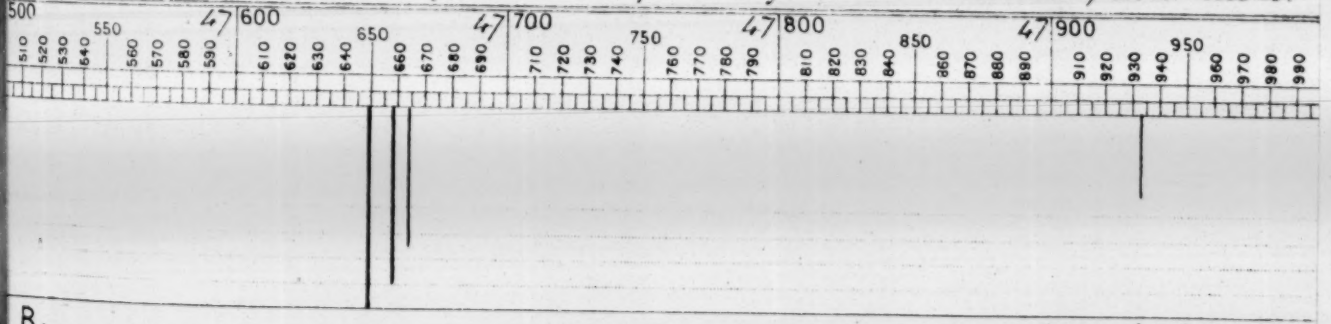
♂ *December 18, 1883. Casella's O tubes at 0.5 and 2.5*



0

Triply test^d for O.

and H *impurities, but showing the O triples brighter than Casella's purer tubes.*

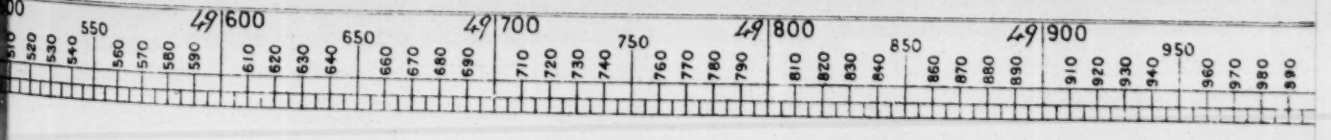


0

R.

Triply test^d for O.

Power = 21.



0

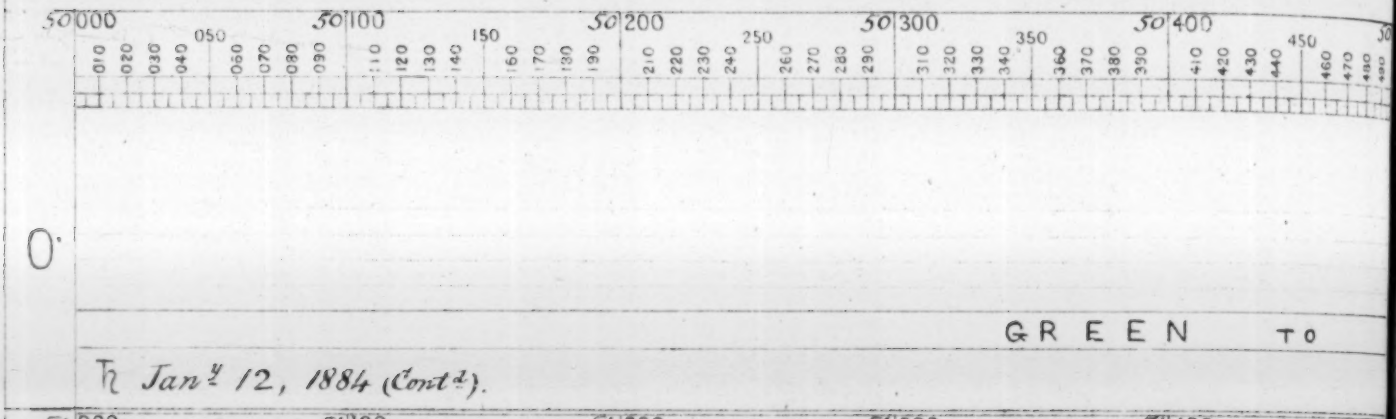
REEN COLOUR.

ion = 48°. Magnifying power = 21.

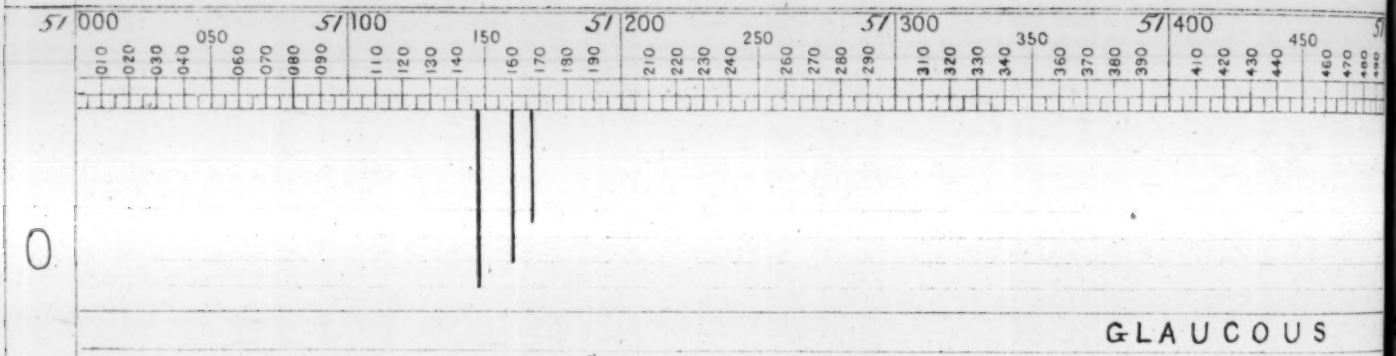
Photo-lith. 1884

T H del 2

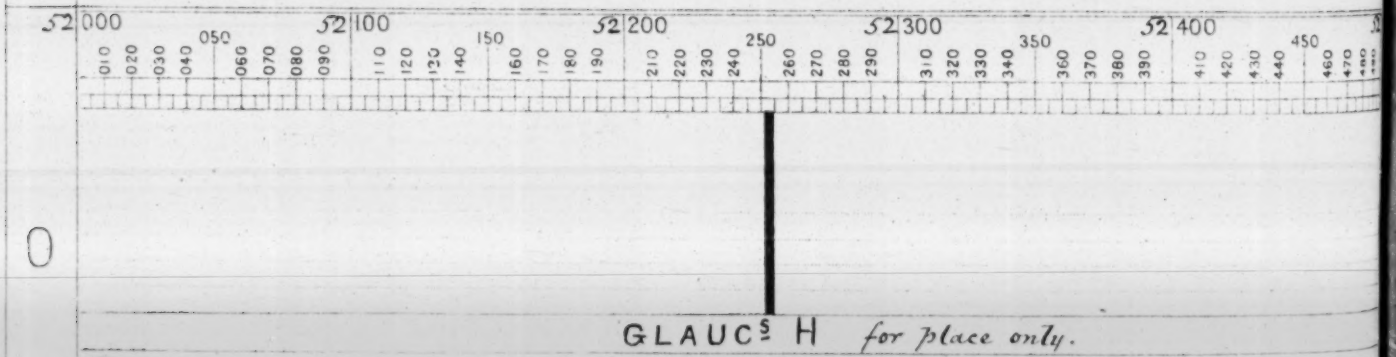
O IN VAC-U



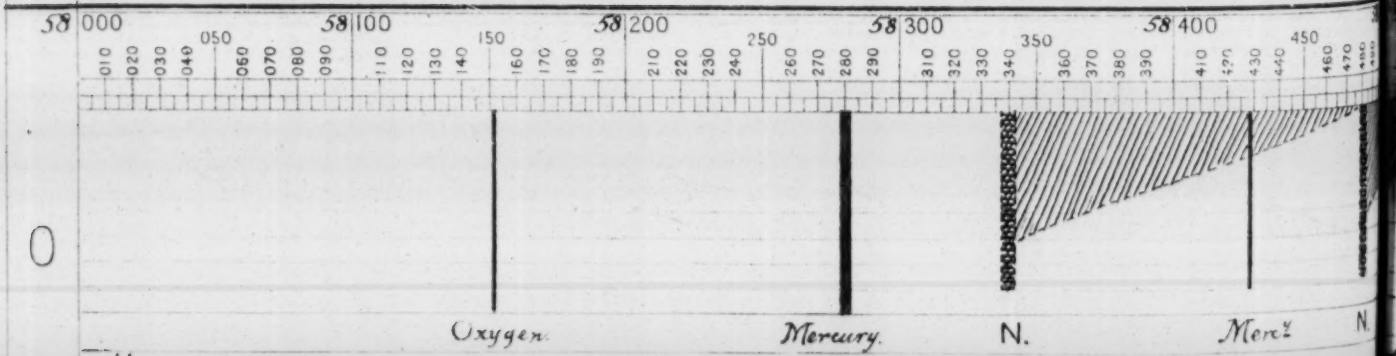
♄ Jany 12, 1884 (Cont^{d}).



♄ Jan^{y}, 12, 1884 (Cont^{d}).



♄ Jany 12, 1884, (Cont^{d}).

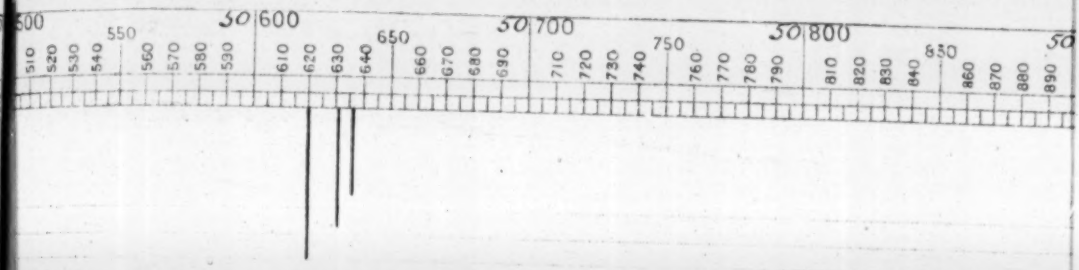


☿ December 26, 1883. Casella's O, H and N tubes, and Sharp's Mercury

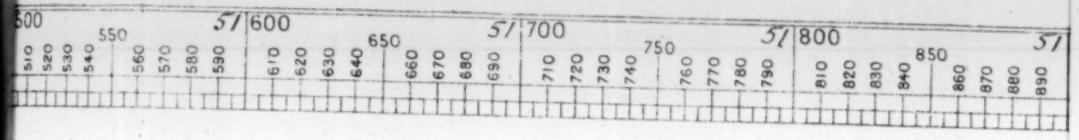
C P S obs & del 1

A Ritchie & Son.

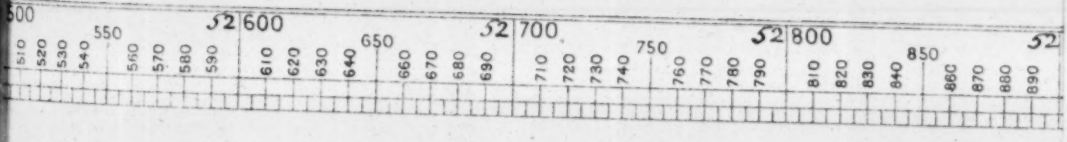
C-UUM - TUBES

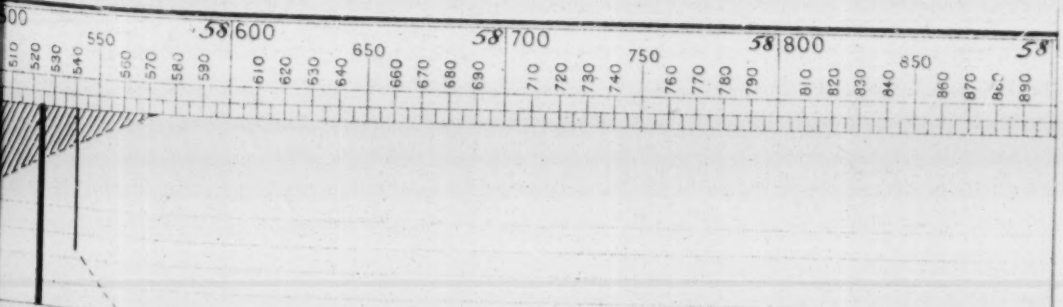


GLAUCOUS COLOUR.



OLOUR.



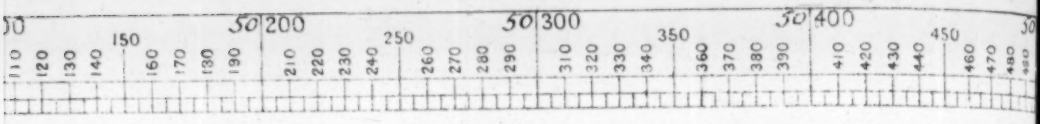


VIOLET H. *Mercury.* VIOLET COLOUR.

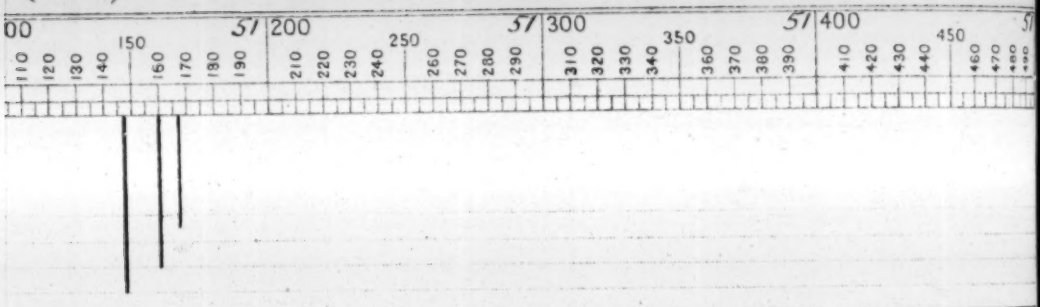
tube. Dispersion = 48°, Magnifying power = 21.

Photo Lith. 1884

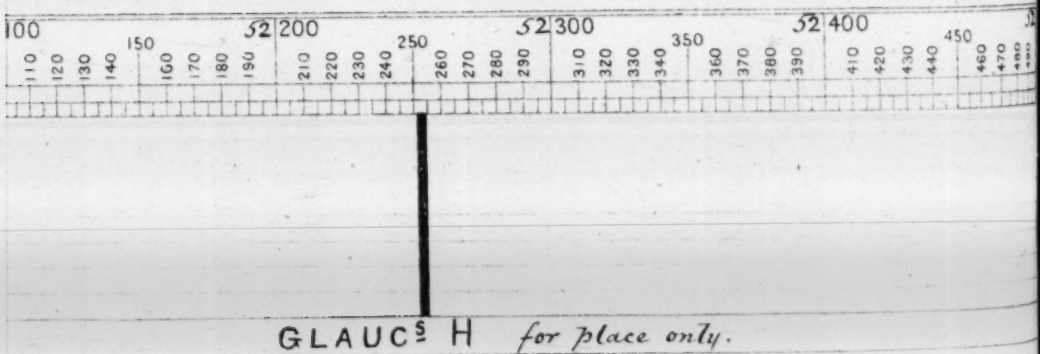
O IN VAC-U



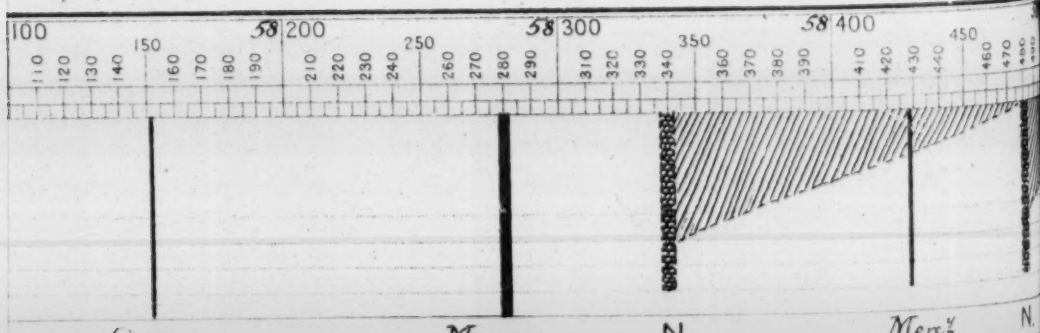
(Cont^d).



84 (Cont^d-).



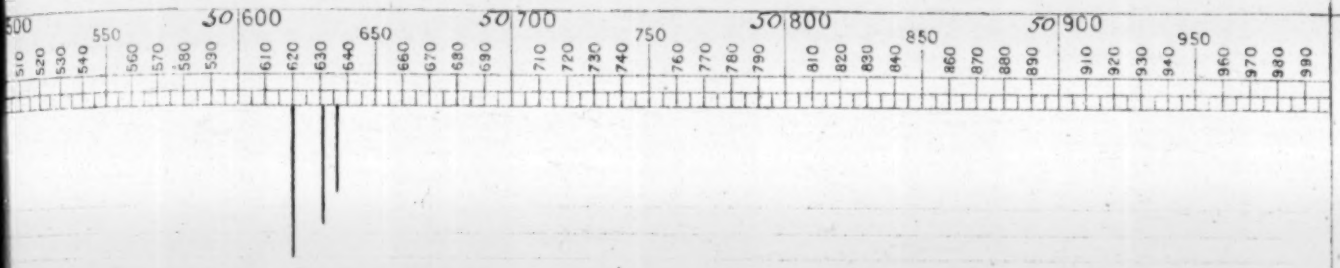
84, (Cont^d).



26, 1883. Casella's O, H and N tubes, and Sharp's Mercury

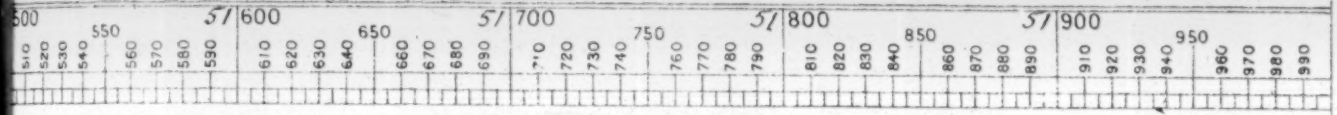
A. Ritchie & Son.

C-UUM-TUBES



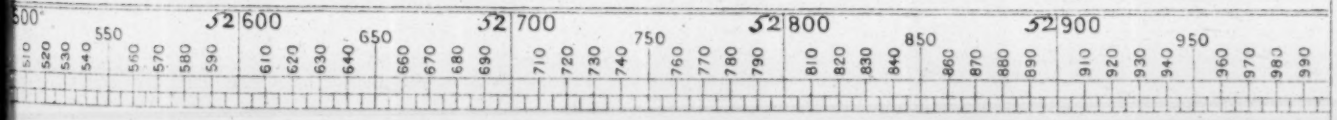
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GLAUCOUS COLOUR.

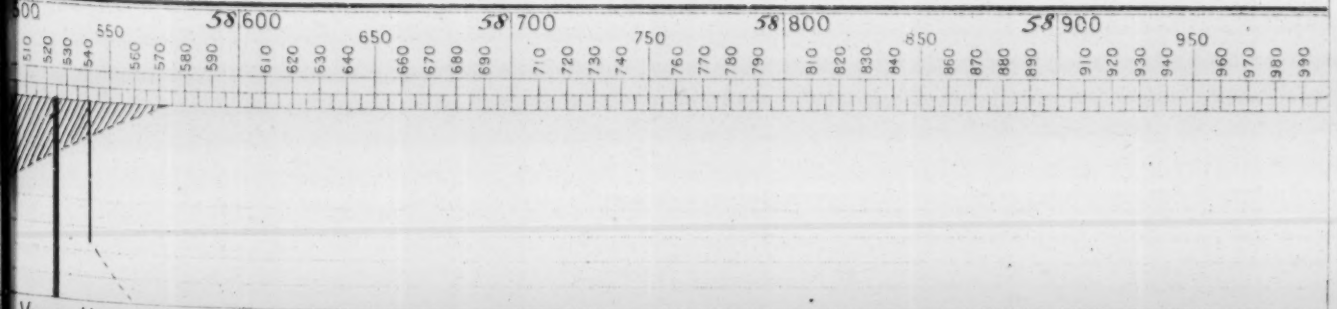


0

OLOUR.



0



0

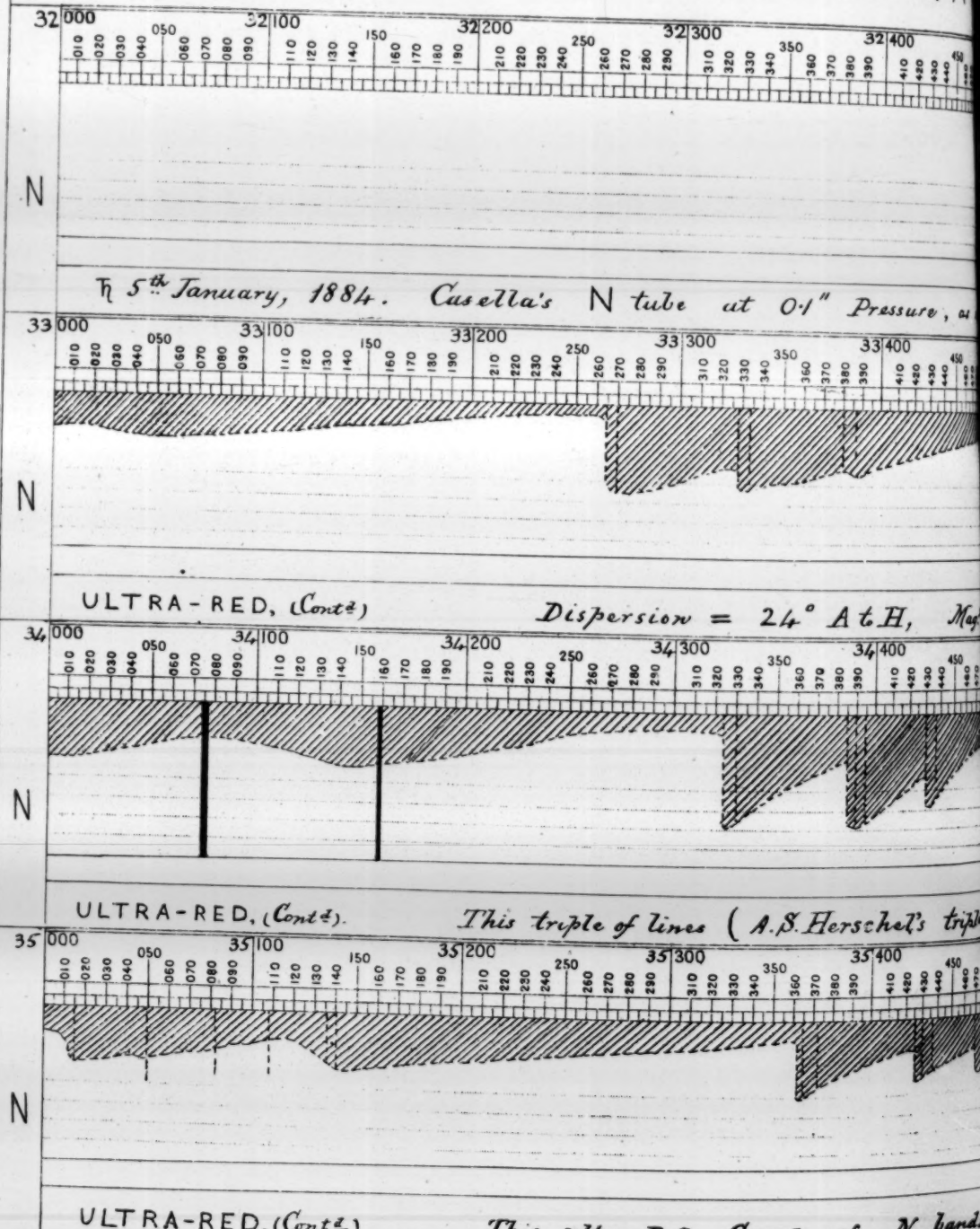
VIOLET H. *Mercury.* VIOLET COLOUR.

tube. Dispersion = 48°, Magnifying power = 21.

Photo-lith. 1884

T H del.

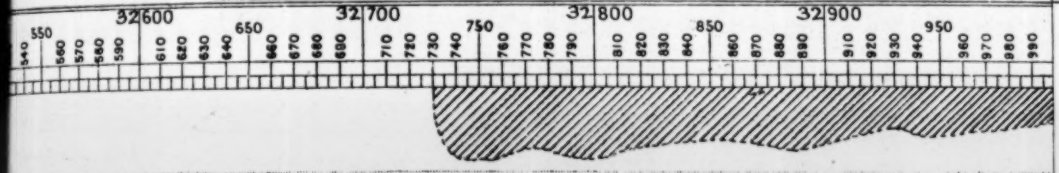
N IN VA



C.P.S. obs. & del. 1.

A. Ritchie & Son.

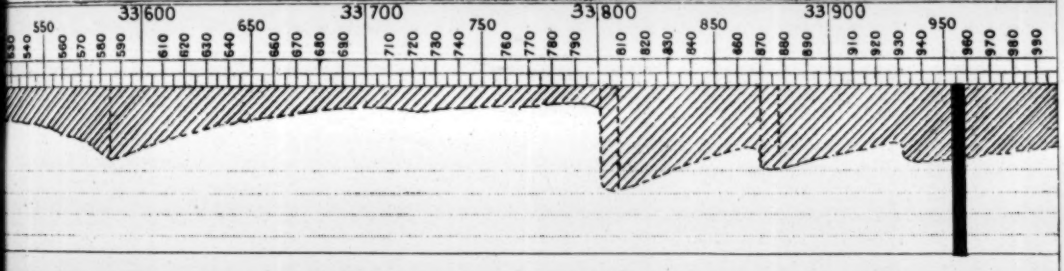
UM - TUBES



N

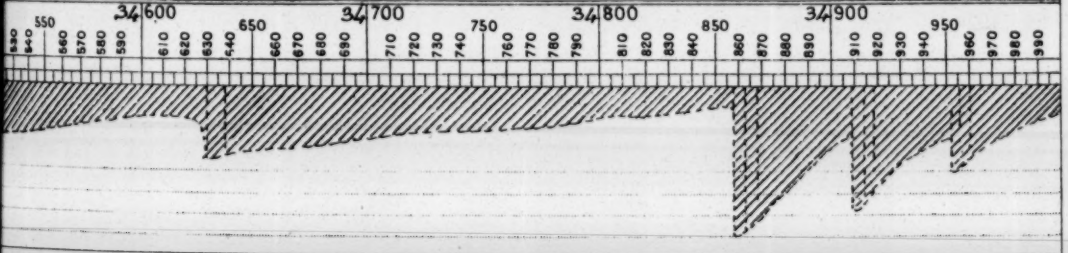
Earliest N band or light perceivable.

Aurora Spectroscope. ULTRA - RED.



N

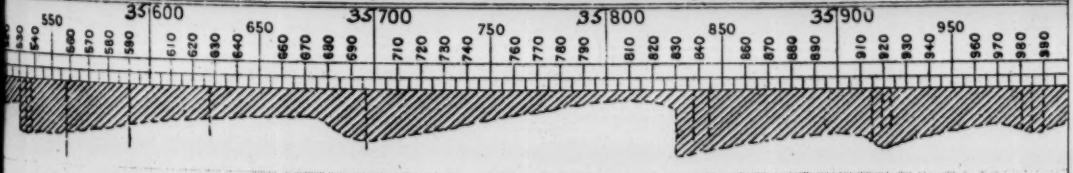
Max. *14.* *This ultra-Red group of bands increasing in intensity.*



N

Max. Intensity for Ultra-Red Group of bands.

triple *55 to 34,158 W.N.Pl. is only seen in tubes of very small Pressure.*



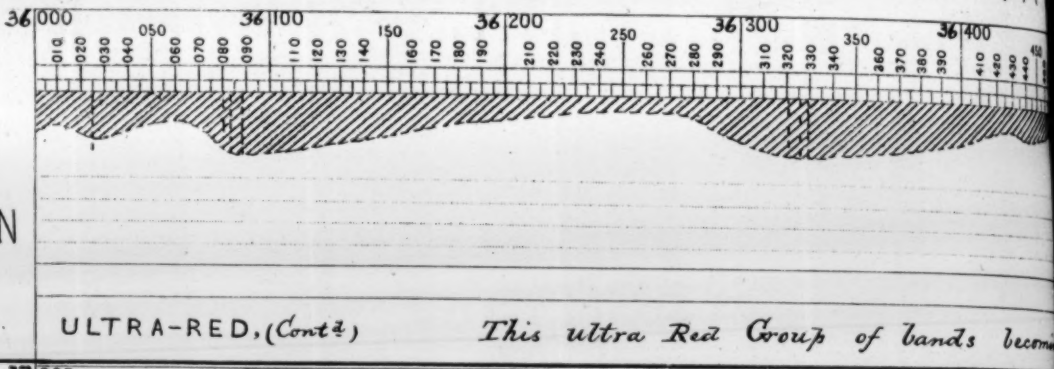
N

ands *ginning to fade again.*

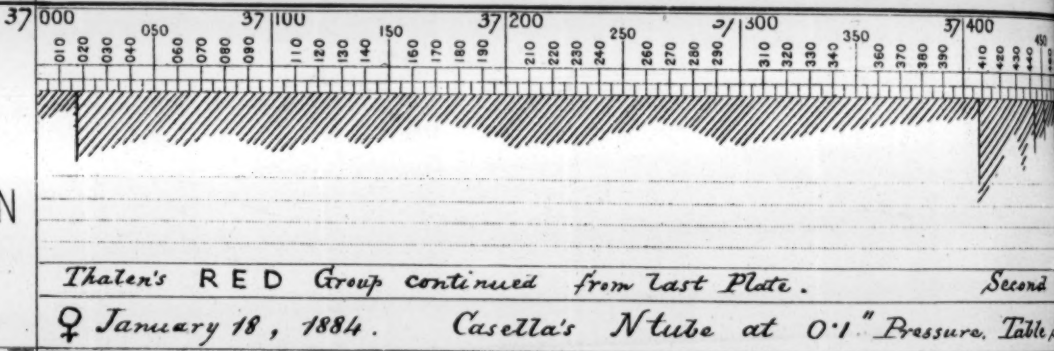
-lith. 1884.

T.H. del. 2.

N IN VA

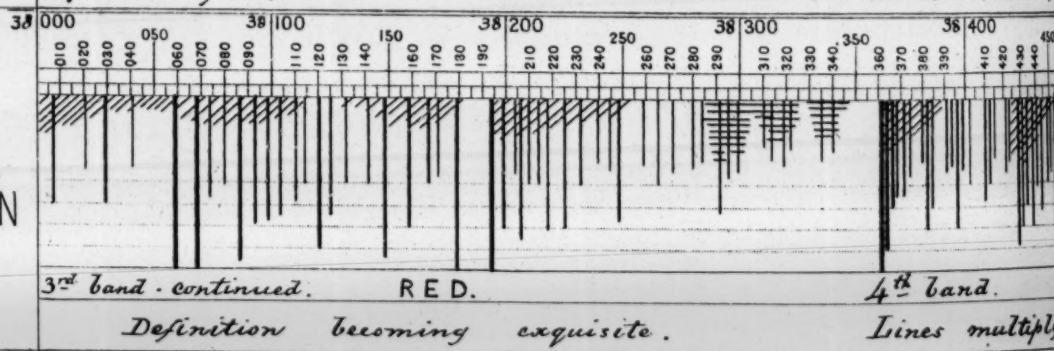


ULTRA-RED, (Cont^d.) *This ultra Red Group of bands becom*



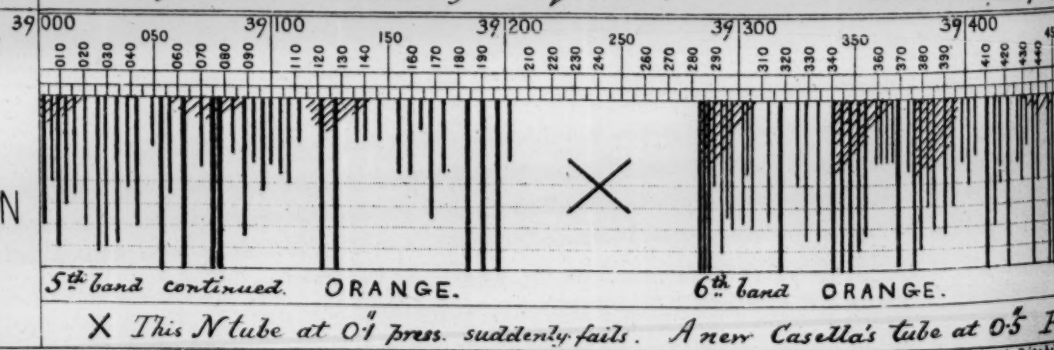
Thalen's RED *Group continued from last Plate.* *Second*

♀ *January 18, 1884.* *Casella's N tube at 0·1" Pressure. Table*



3rd *band continued.* RED. 4th *band.*

Definition becoming exquisite. *Lines multiplying*



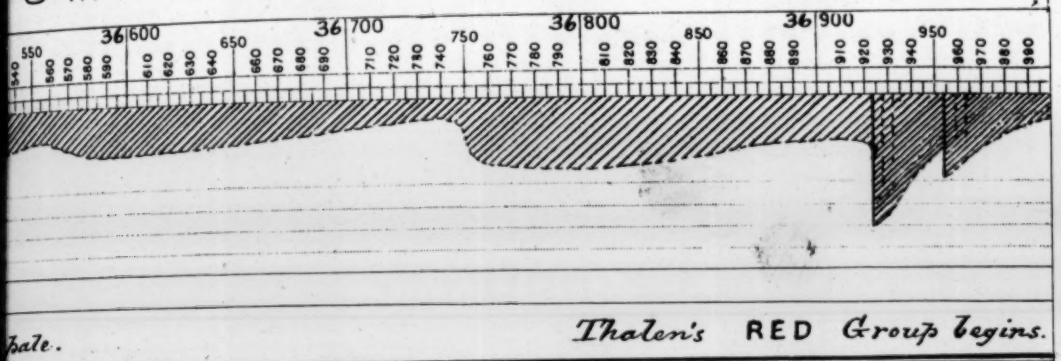
5th *band continued.* ORANGE. 6th *band* ORANGE.

× *This N tube at 0·1 press. suddenly fails. A new Casella's tube at 0·5 Pres.*

C.P.S. obs. & del. I.

A. Ritchie & Son

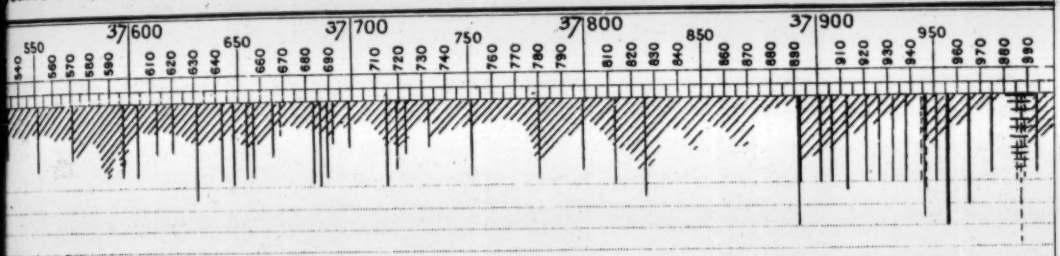
UM - TUBES



N

Thalen's **RED** *Group begins.*

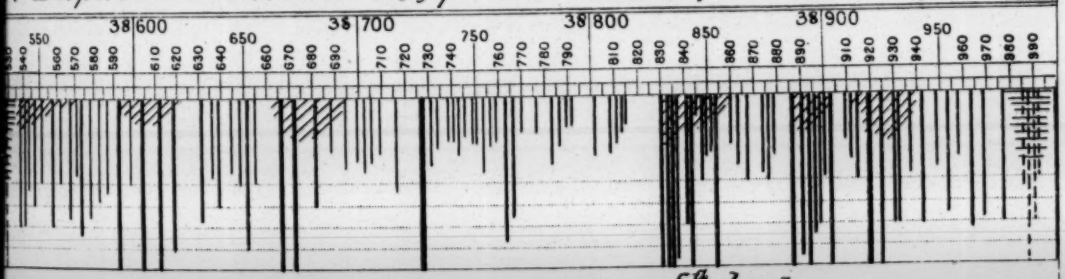
bale.



N

Thalen's Group. **RED.** *3rd band of Thalen's Gr.*

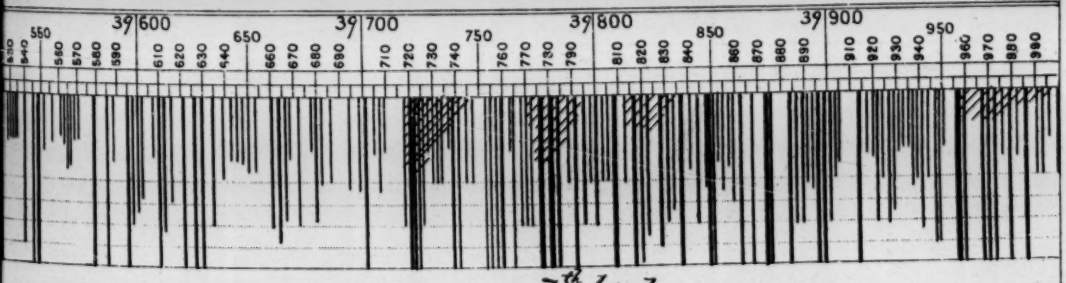
. Dispersion = 60° A to H. Mag.l p. = 21. *Coil's sparks 3" to 5" long.*



N

5th band.

ARLET COLOUR.



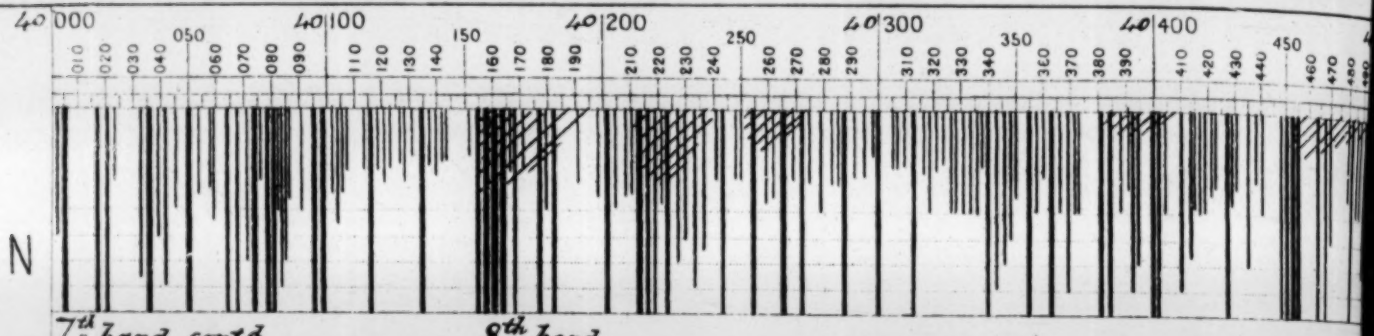
N

7th band.

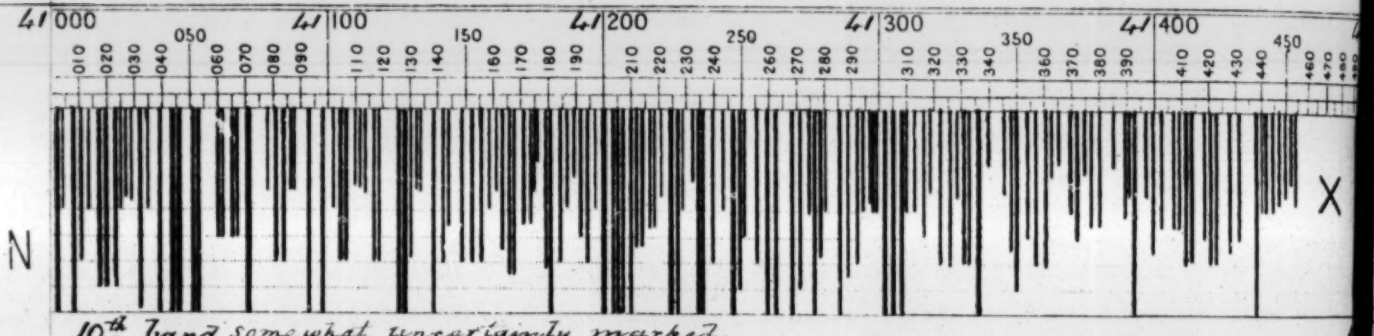
d instead through all the subsequent work.

-lith. 1884. *T. H. del. 2.*

N IN VAC-U



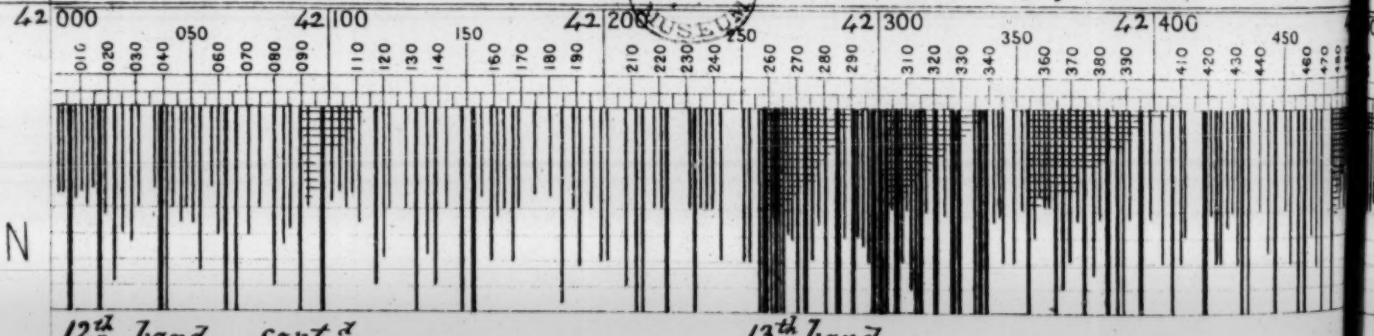
YELLOW.



YELLOW.

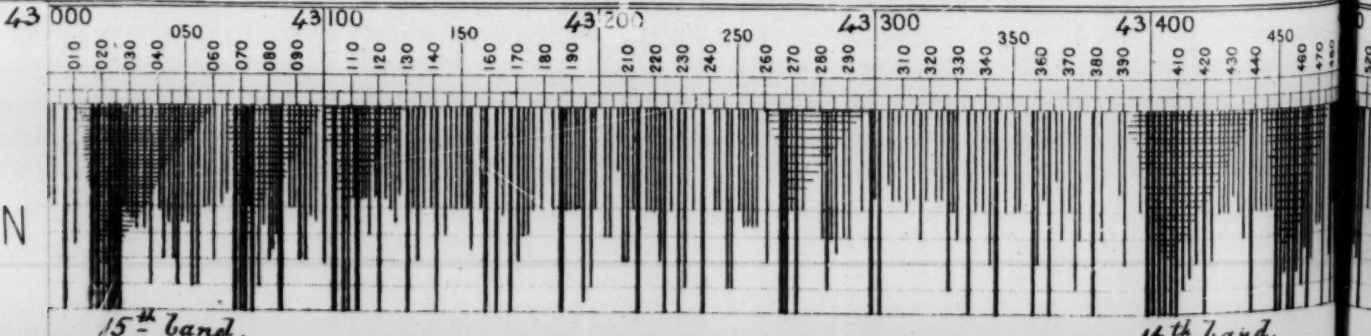
BRITISH MUSEUM 4 JUL 8

X An inaccuracy of Absolute Place.



♂ Jan.y 22, cont.d. Prismatic Disp.n = 60° A to H. Mag.y p. = 21.

CITR



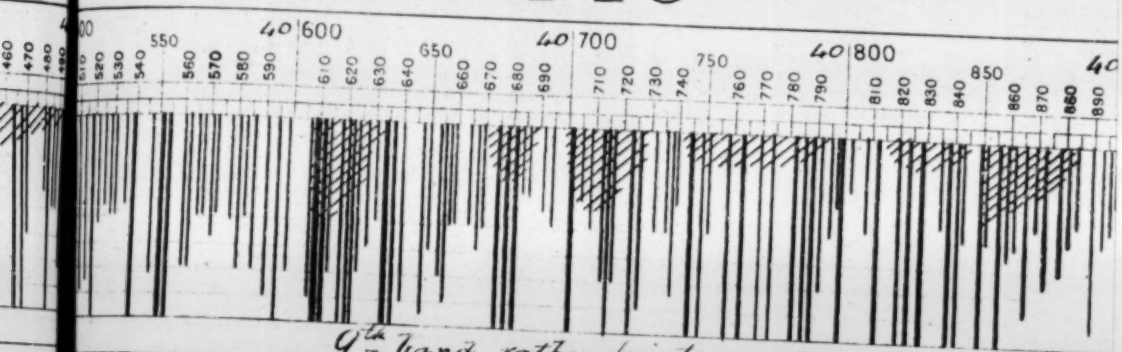
♂ January 22, 1884, (Cont.d)

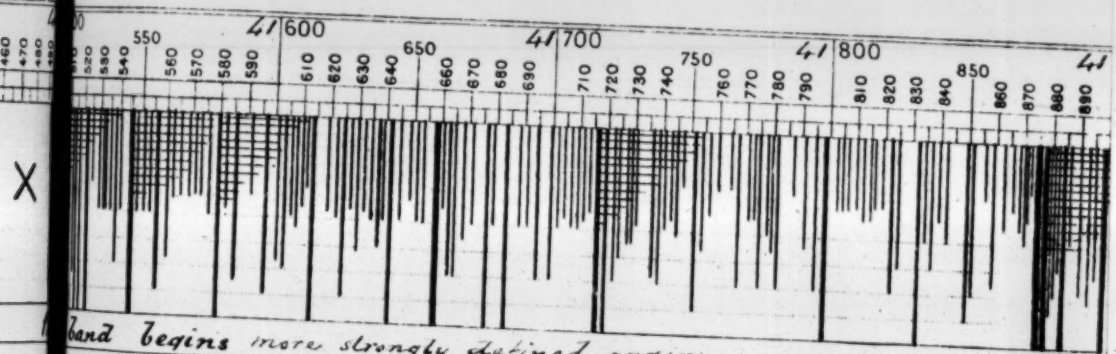
CITRON COLOUR.

C.P.S. del. et lith. I.

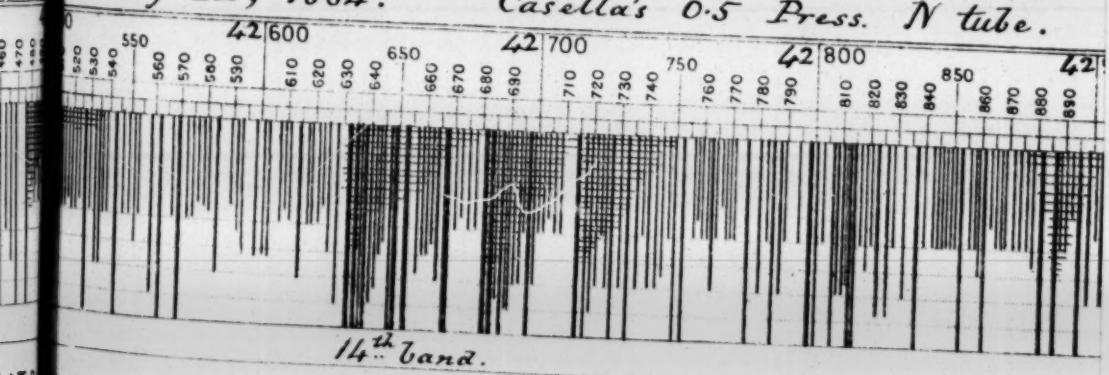
A. Ritchie & Son. Photo-Lith.

C-UUM-TUBES





January 22, 1884. Casella's 0·5 Press. N tube.



COLOUR. Closeness and definition of the constituent line

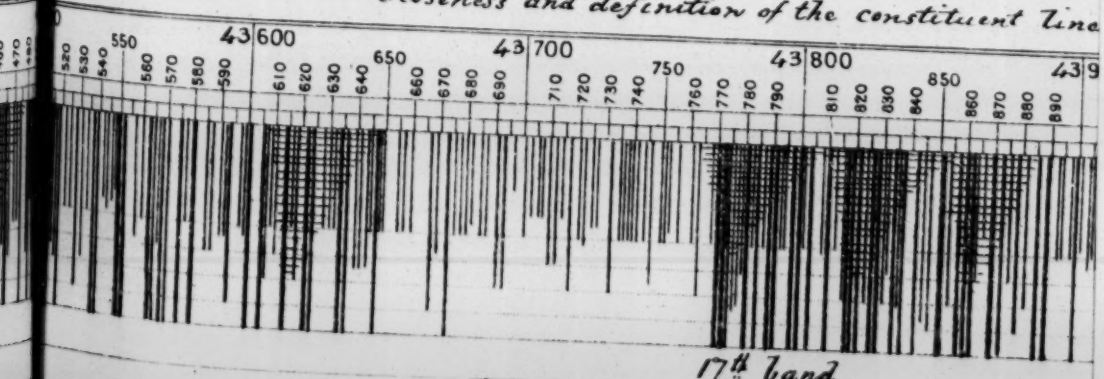
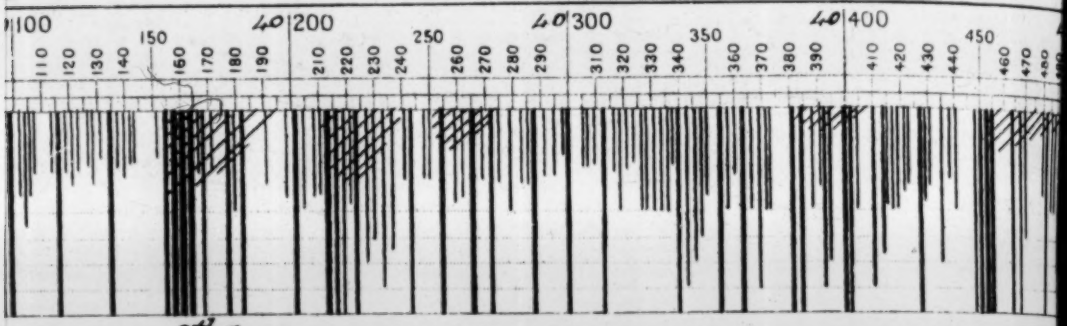
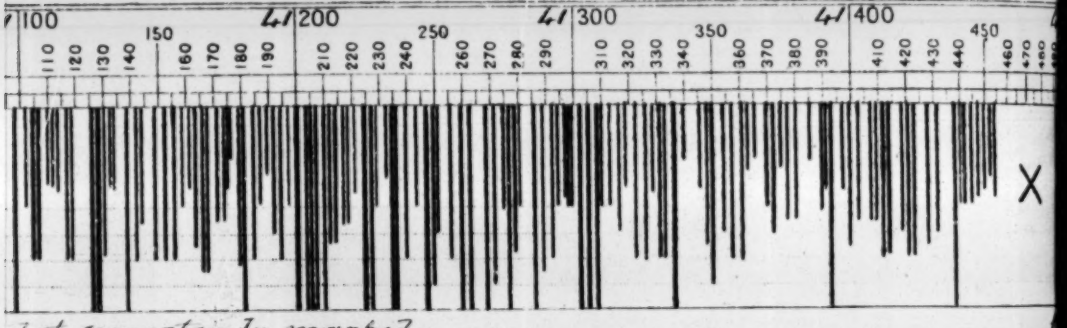


Photo-Lith. 1884

N IN VAC-U



8th band.



X

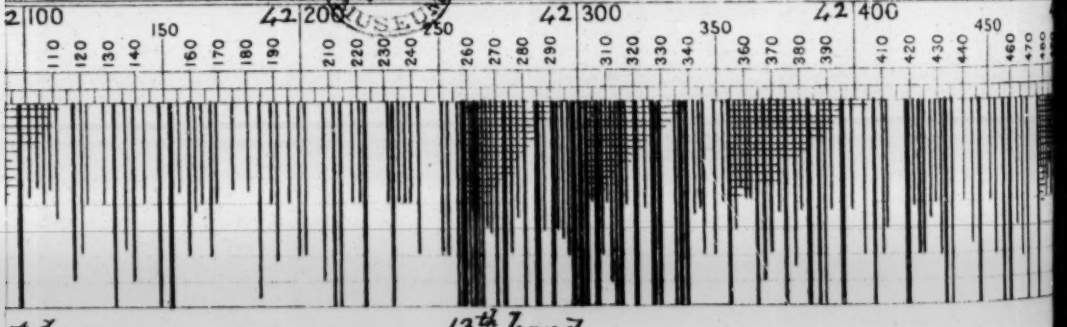
what uncertainly marked.

band

BRITISH MUSEUM 4 JUS7

X An inaccuracy of Absolute Place.

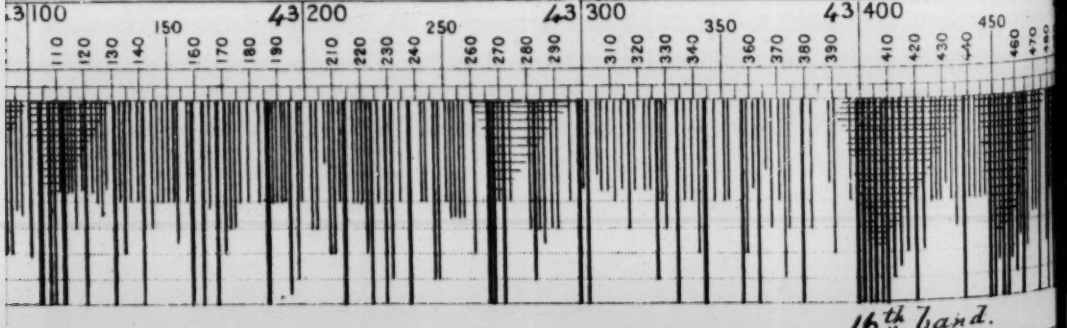
Janua



13th band.

Prismatic Disp= 60° A to H. Mag^n p. = 21.

CITR COL



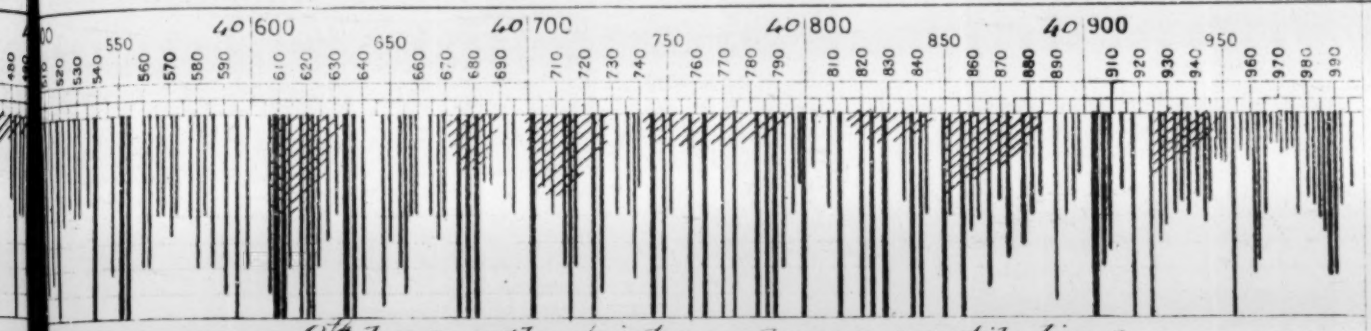
16th band.

1884, (Cont^d)

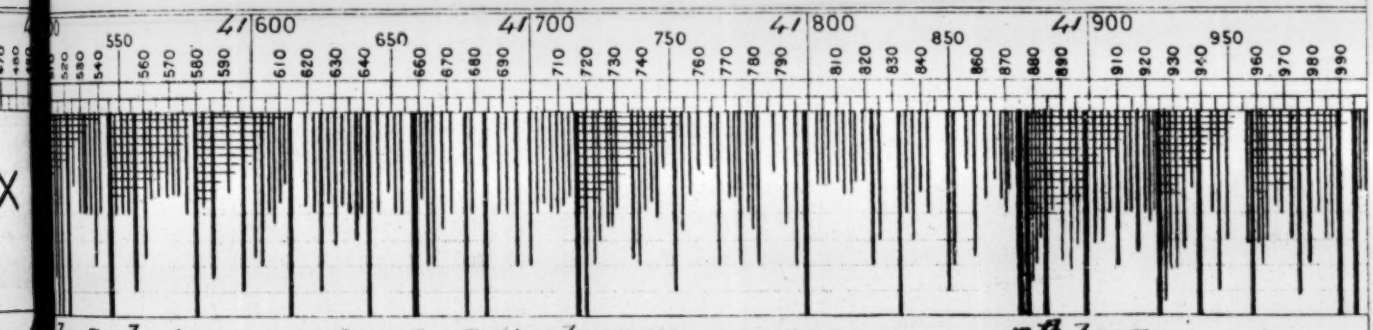
CITRON COLOUR.

A. Ritchie & Son. Photo-Lith

-UUM - TUBES

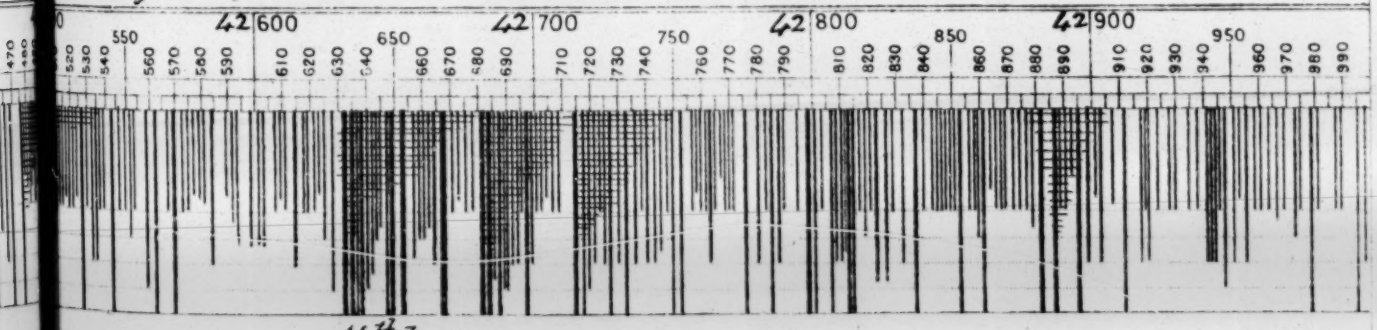


9th band, rather fainter and more scantily lined.



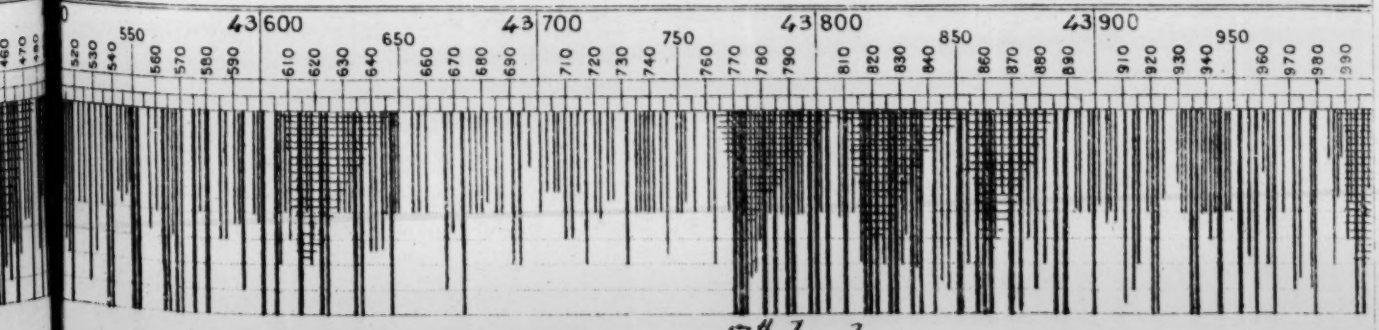
band begins more strongly defined again. 12th band.

January 22., 1884. Casella's 0·5 Press. N tube.



14th band.

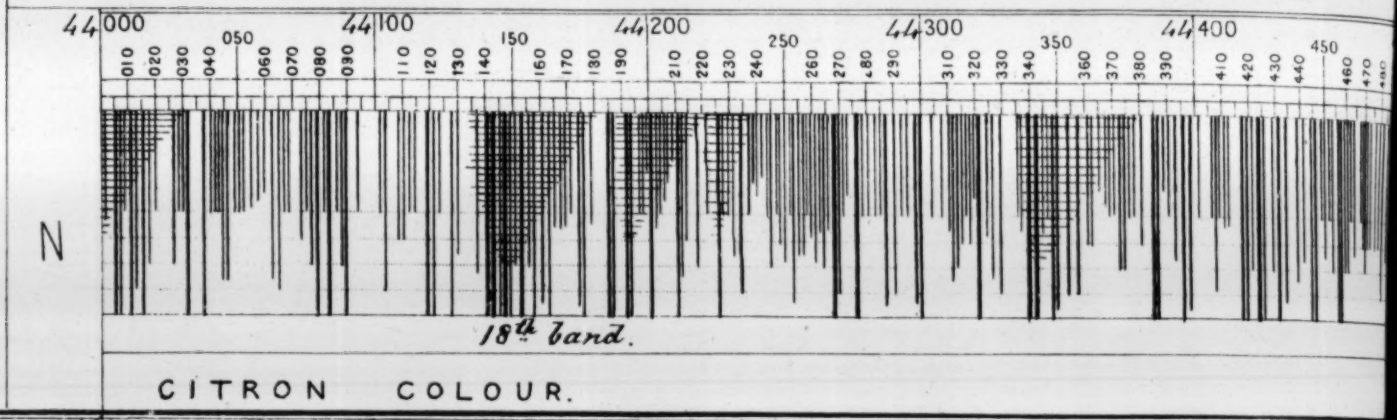
COLOUR. Closeness and definition of the constituent lines inconceivable.



17th band.

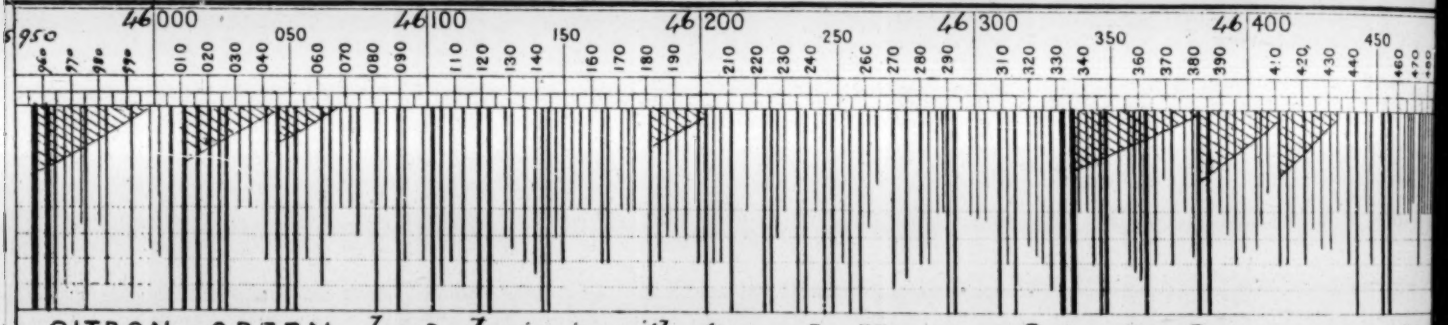
Photo-Lith. 1884

N IN VAC-U



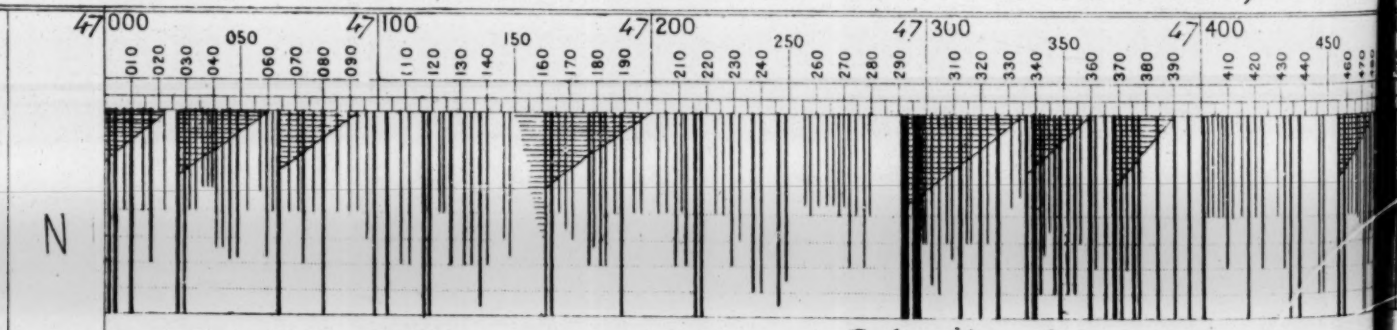
18th band.

CITRON COLOUR.



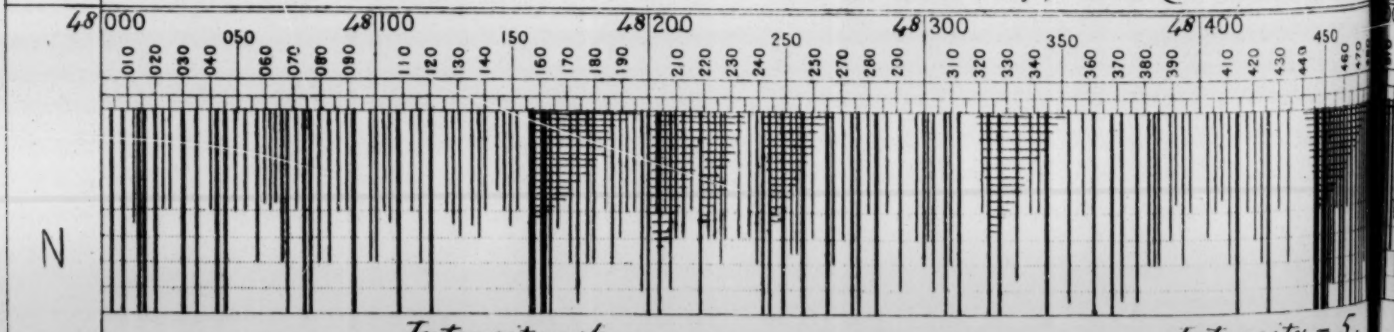
CITRON GREEN bands beginning with strong doubles. Intensity = 3.

☾ 4th. February 1884. Casella's 0·5" Brass. N tube. Prismatic Disp.= 60° A



Intensity = 6.

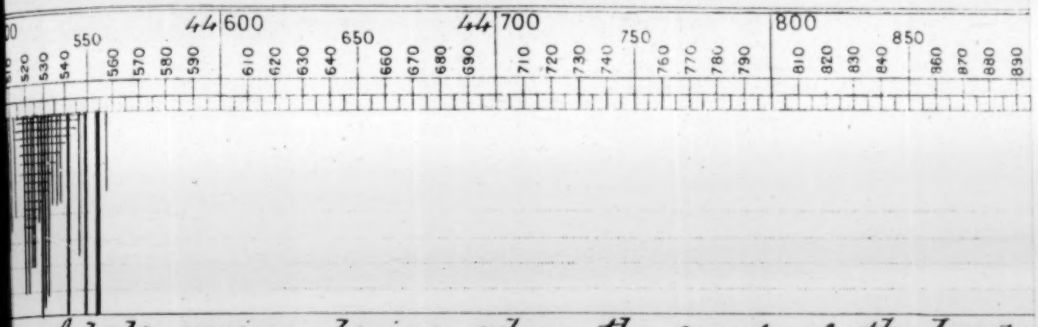
GREEN COLOUR. ☾ 4th February, 1884 (Continued).



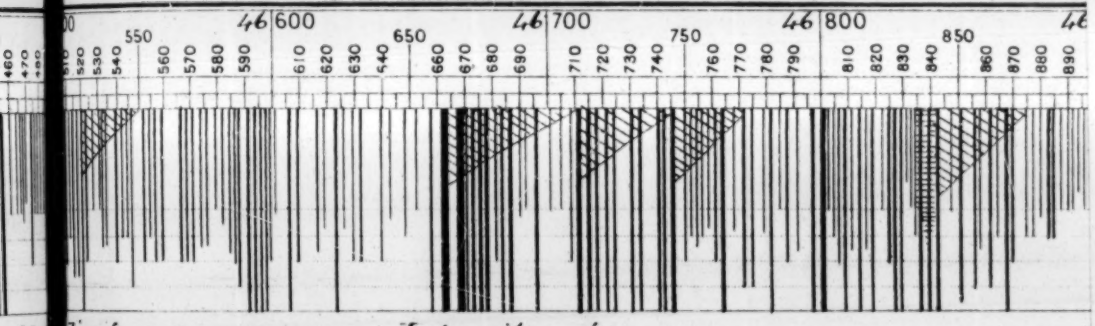
Intensity = 4. Intensity = 5.

☾ 4th. February 1884, (Continued.) GREEN COLOUR

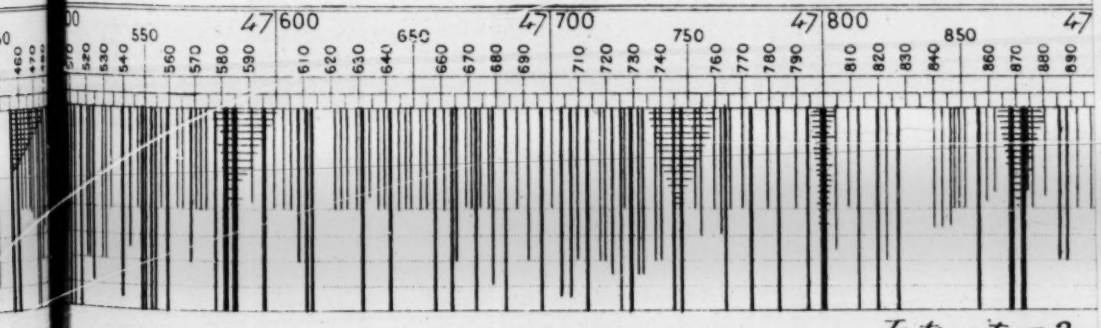
C-UUM - TUBES



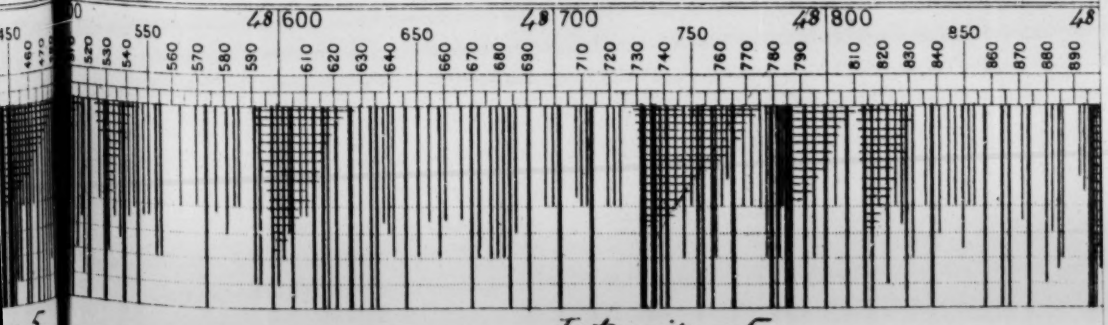
A pale region begins, where the count of the bands



line for reference. Intensity = 4.



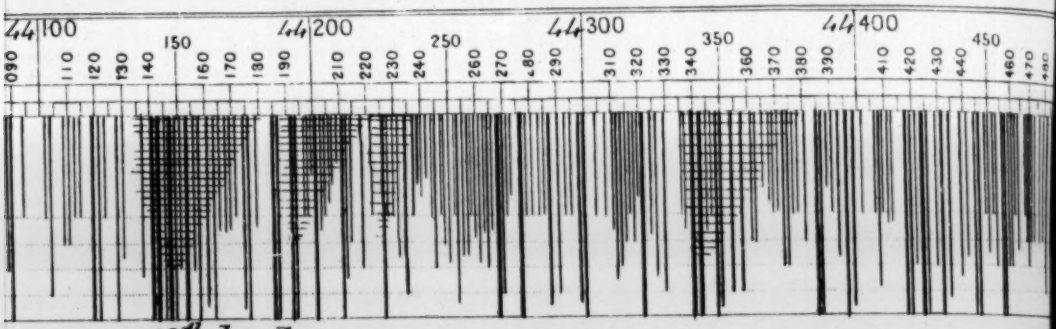
Intensity = 2.



Intensity = 5.

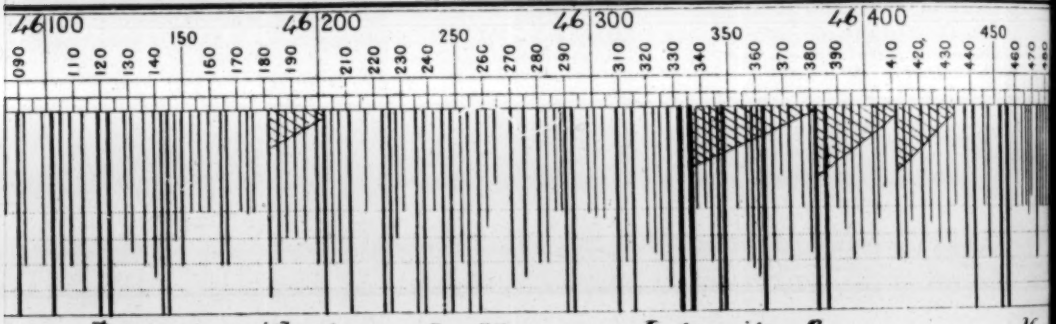
Photo-lith. 1884.

N IN VAC-U



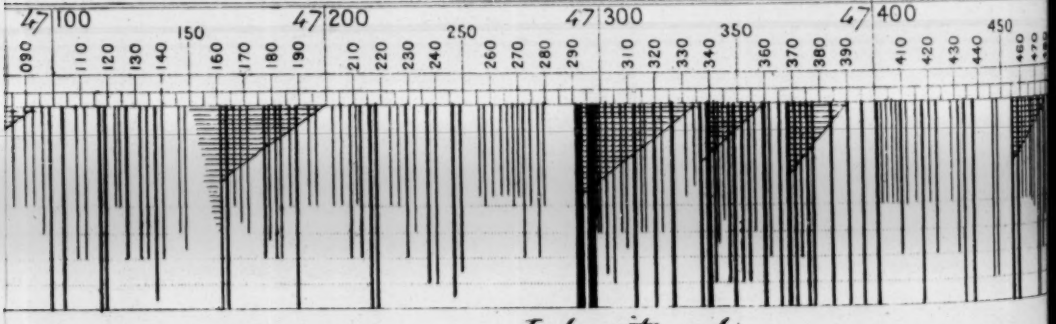
18th band.

COLOUR.



ands beginning with strong doubles. Intensity = 3.

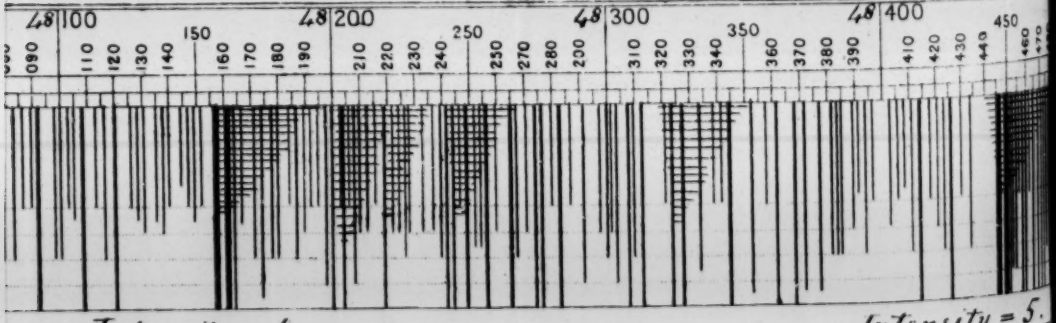
184. Casella's 0·5" Press. N tube. Prismatic Disp.= 60° A



Intensity = 6.

COLOUR.

(4th February, 1884 (Continued).



Intensity = 4.

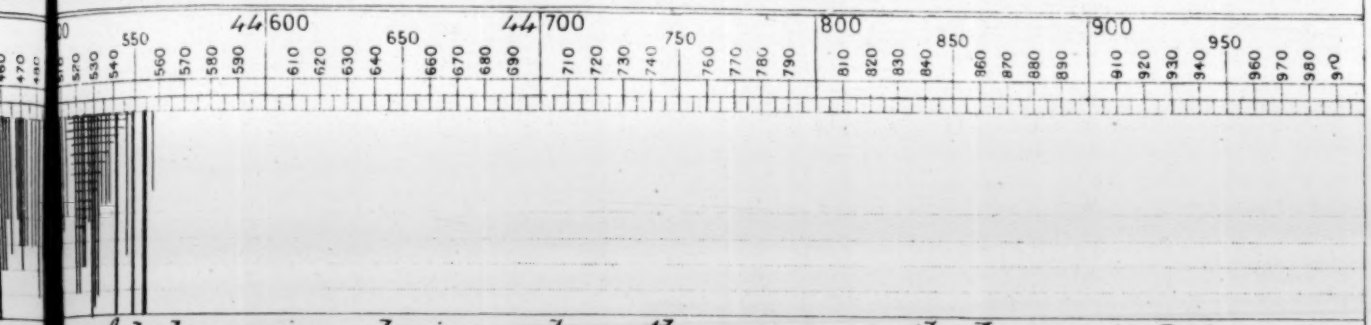
Intensity = 5.

ary 1884, (Continued.)

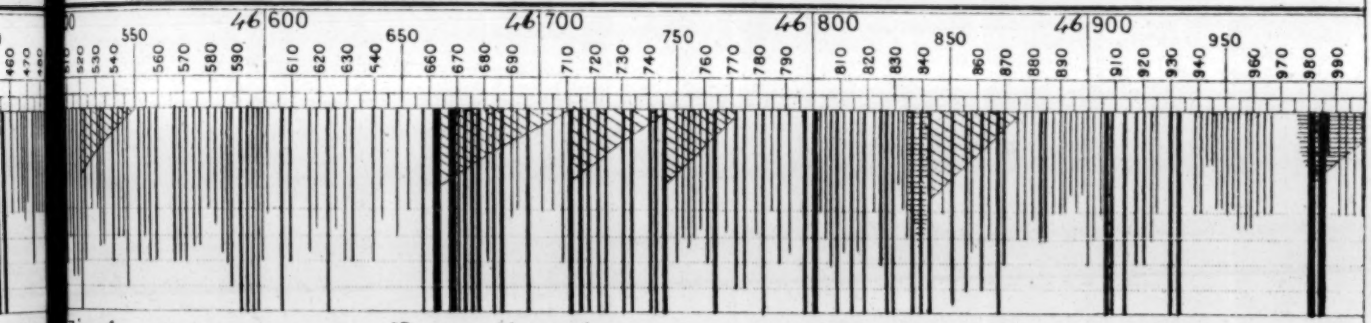
GREEN COLOUR

A. Ritchie & Son,

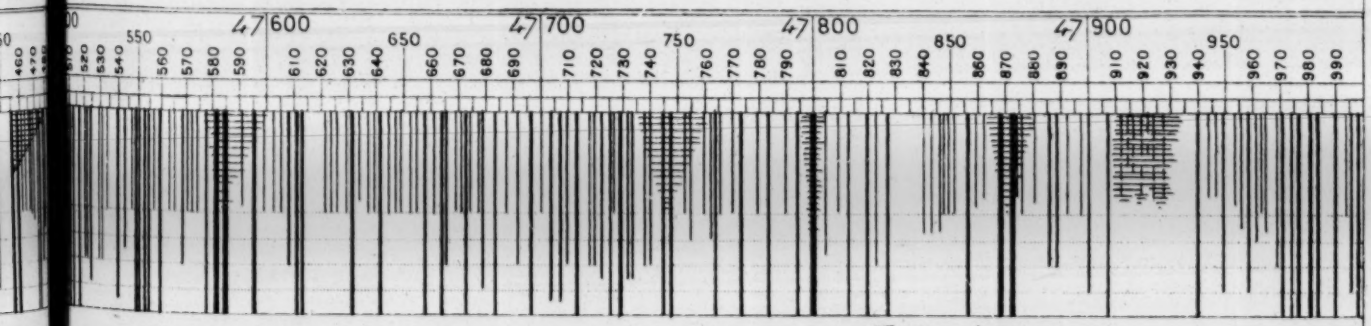
C-UUM - TUBES



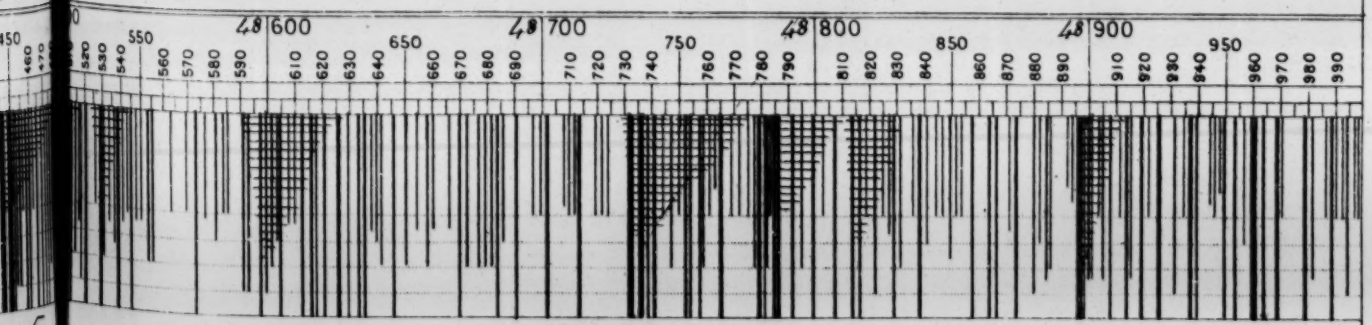
A pale region begins, where the count of the bands is lost.



Line for reference. Intensity = 4. Intensity = 5.



Intensity = 2.

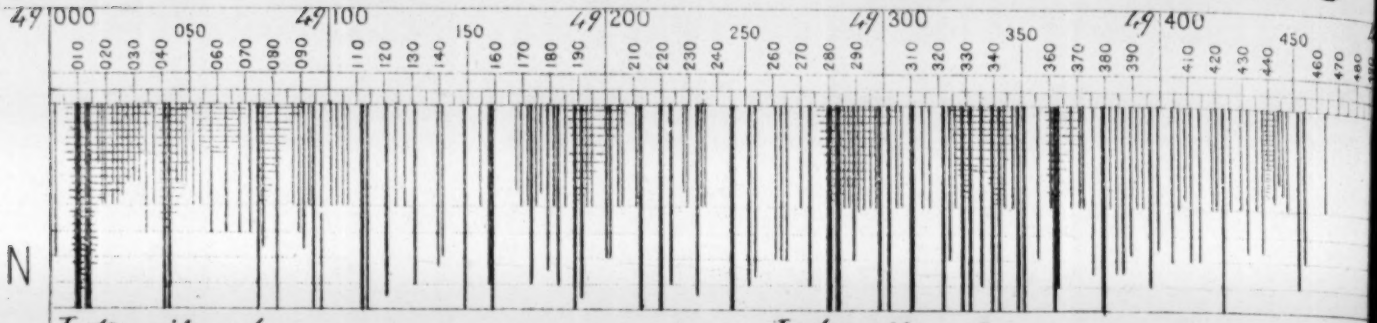


Intensity = 5.

Photo-lith. 1884

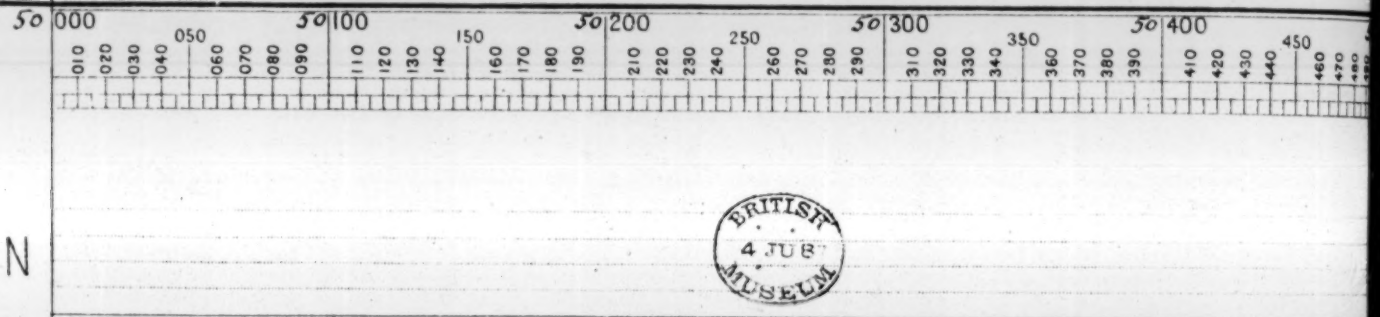
T.H del 2.

N IN VAC-U



Intensity = 4. Intensity = 3.

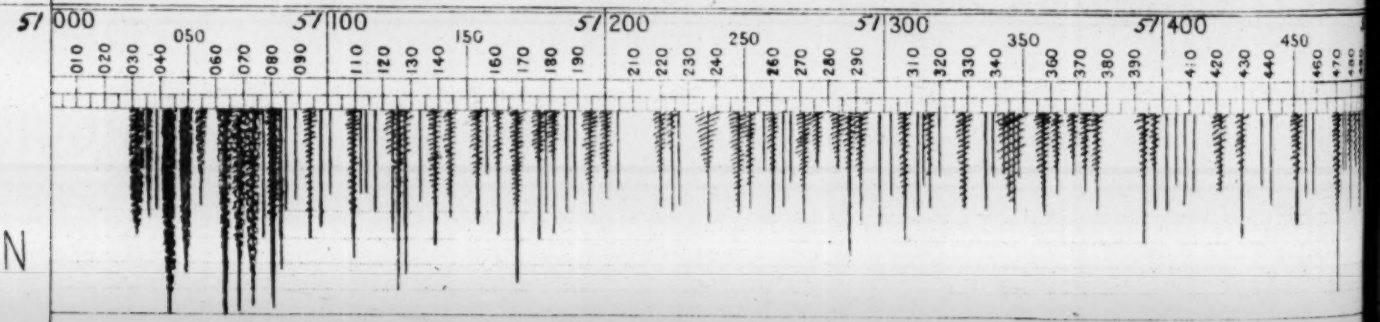
GREEN COLOUR. ☾ 4th Feb. 1884, (Continued).



BRITISH 4 JUB MUSEUM

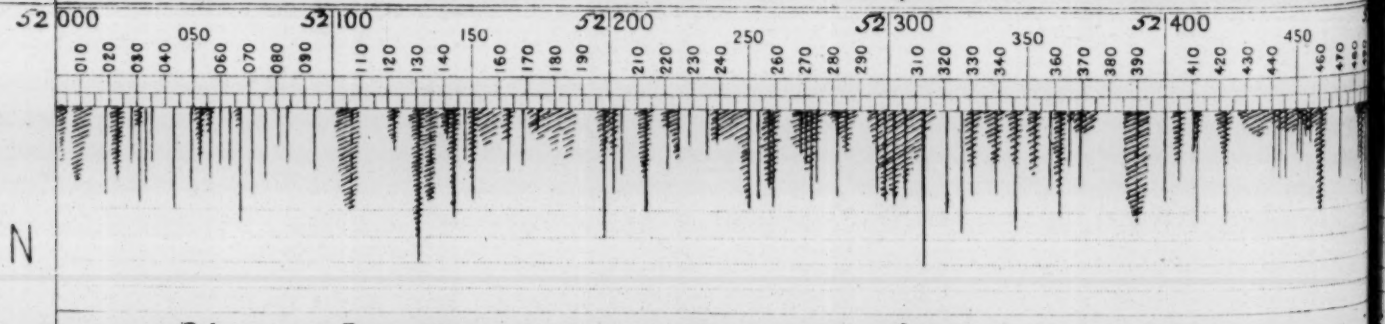
GLAUCOUS COLOUR

This portion not fully and finally observed; but in it are the faint endings of the



One of the broad blue, or Glaucous blue, bands. The lines beginning to sho

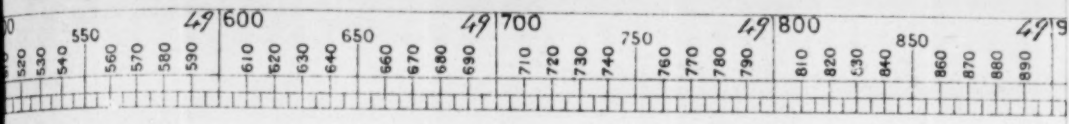
☾ March 10, 1883. Prismatic Dispersion = 48° A to H.

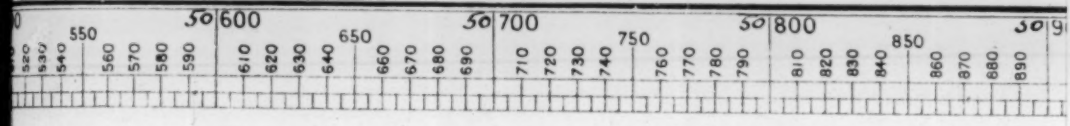


Lines hereabouts very hazy and faint.

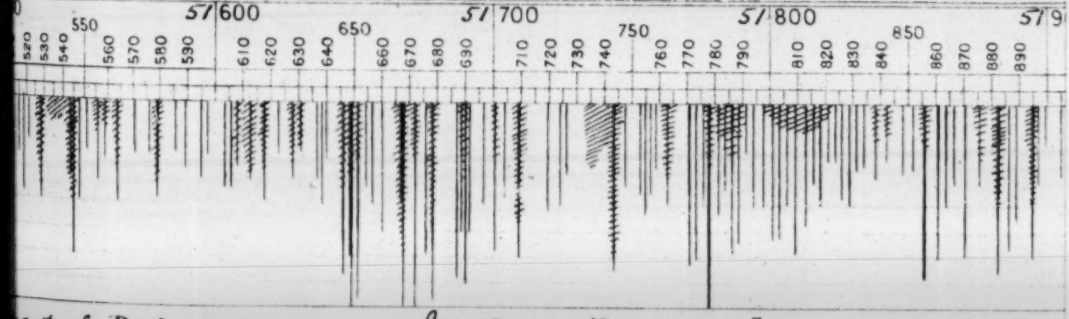
☾ March 10 (Contd) GLAUCOUS BLUE COLOUR.

C-UUM - TUBES



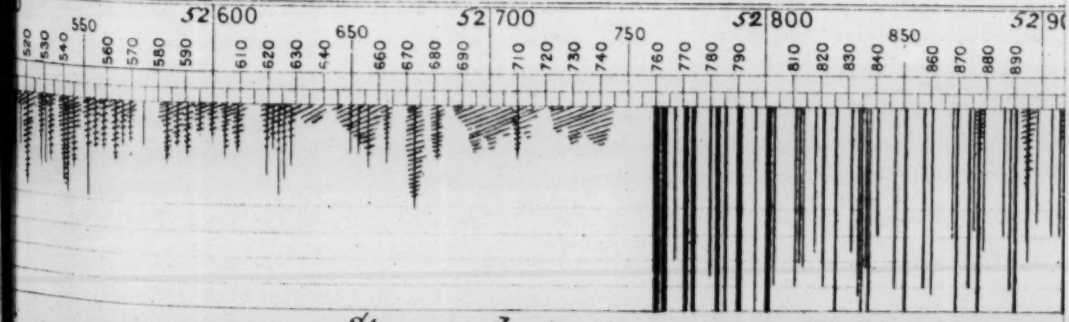


ier narrow N bands, and faint beginnings of the broader, later or



ant of Definition. Another Glaucous-blue and broad ban

power = 21.

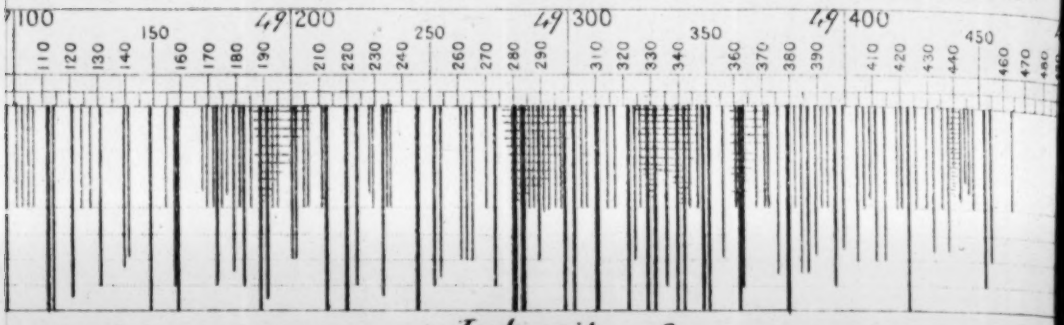


Strong beginning and well defined, of a

BLUE - BAND.

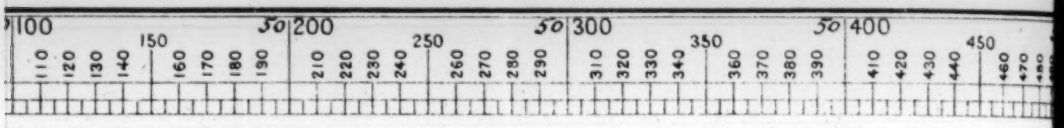
Photo-lith. 1884.

N IN VAC- U



Intensity = 3.

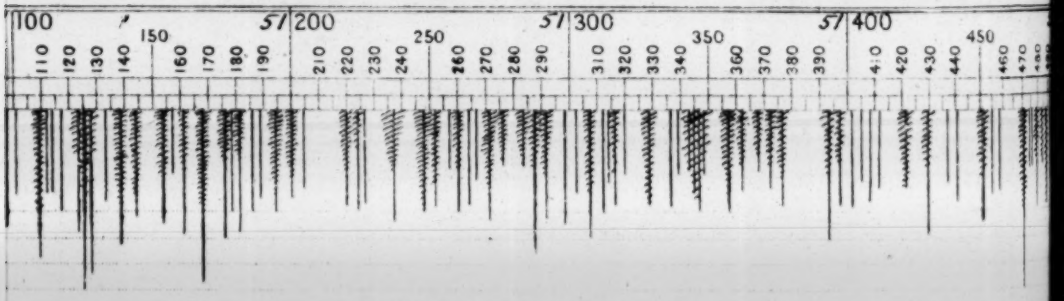
OLOUR. *C 4th Feb. 1884, (Continued).*



BRITISH
4 JUB
MUSEUM

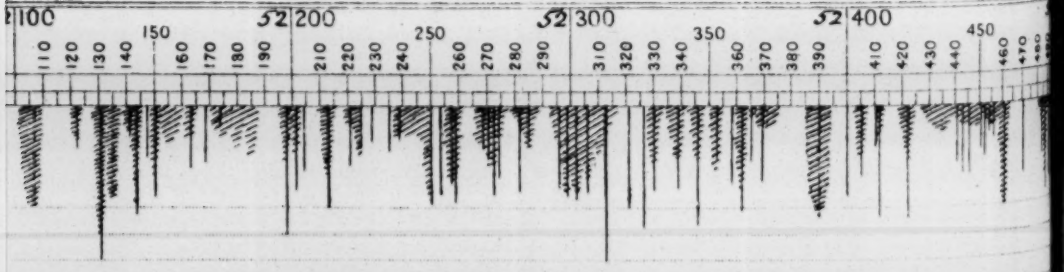
GLAUCOUS COLOUR

This portion not fully and finally observed; but in it are the faint endings of the



road blue, or Glaucous blue, bands. The lines beginning to sho

, 1883. Prismatic Dispersion = 48° A to H.

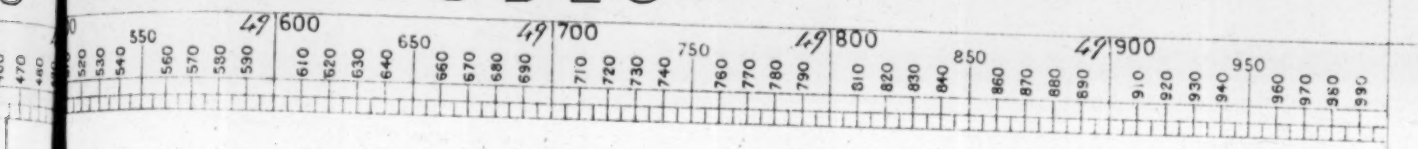


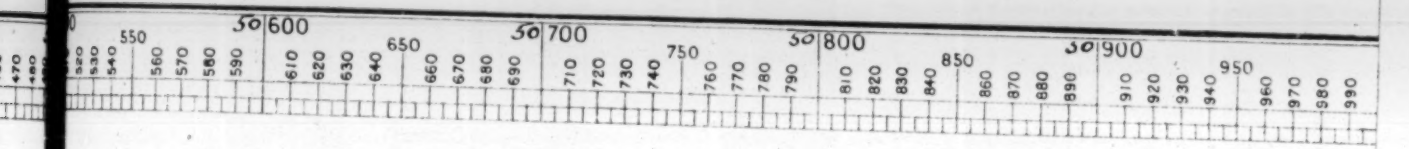
hereabouts very hazy and faint.

(Cont^d) GLAUCOUS BLUE COLOUR.

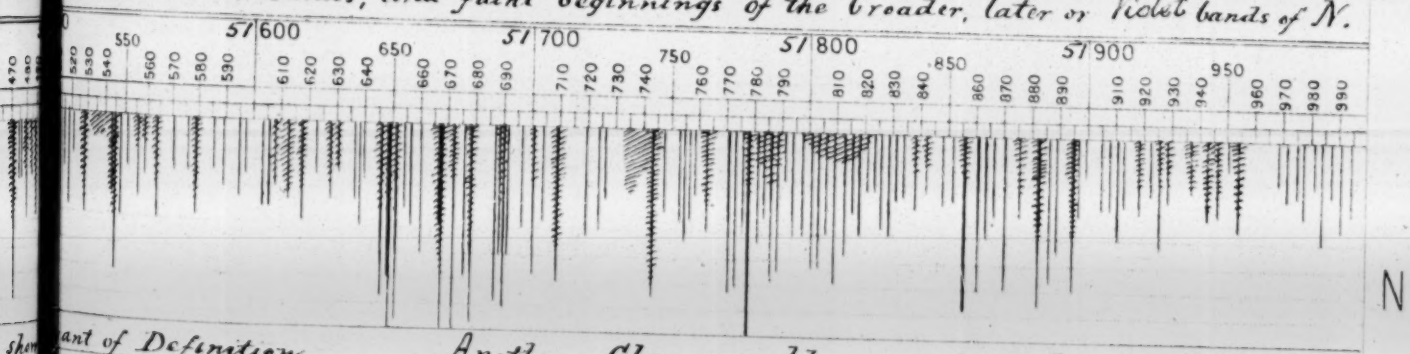
A. Ritchie & Son.

C-UUM - TUBES



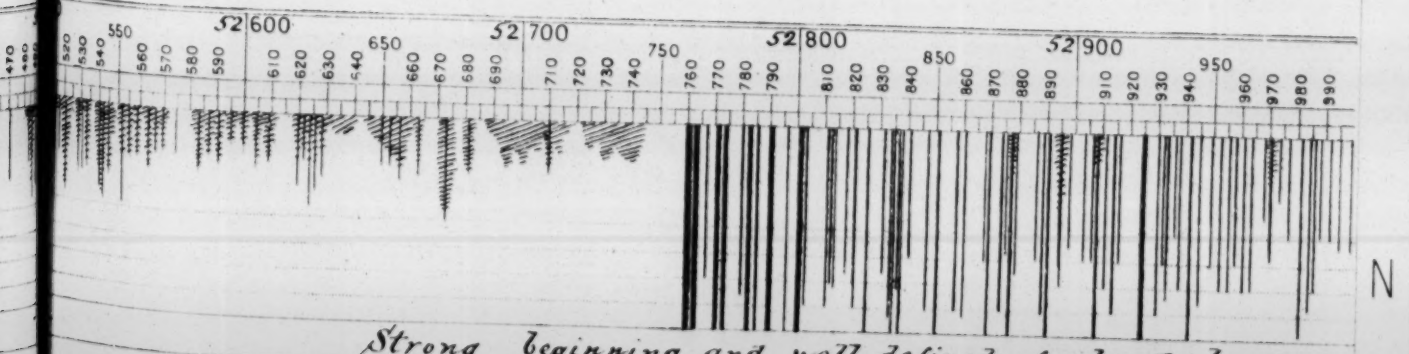


ier narrow N bands, and faint beginnings of the broader, later or violet bands of N.



ant of Definition. Another Glaucous-blue and broad band begins.

power = 21.



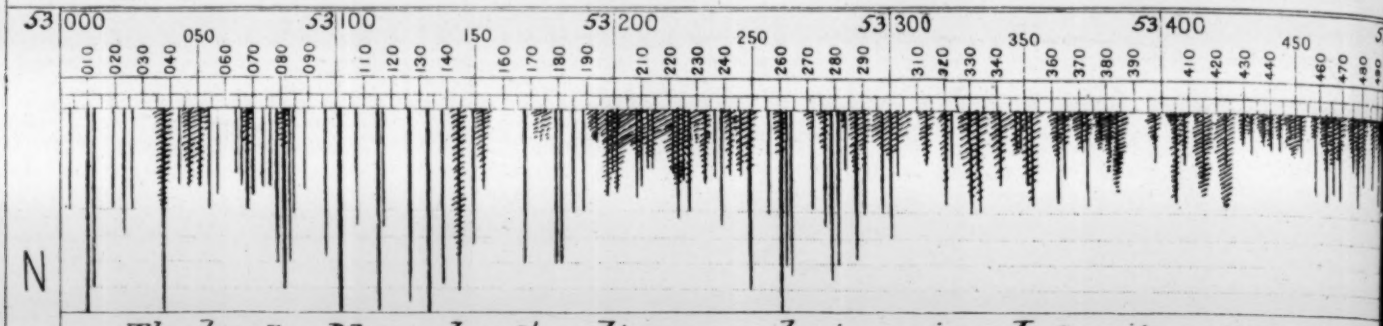
Strong beginning and well defined, of a broad band.

BLUE - BAND.

Photo-lith. 1884

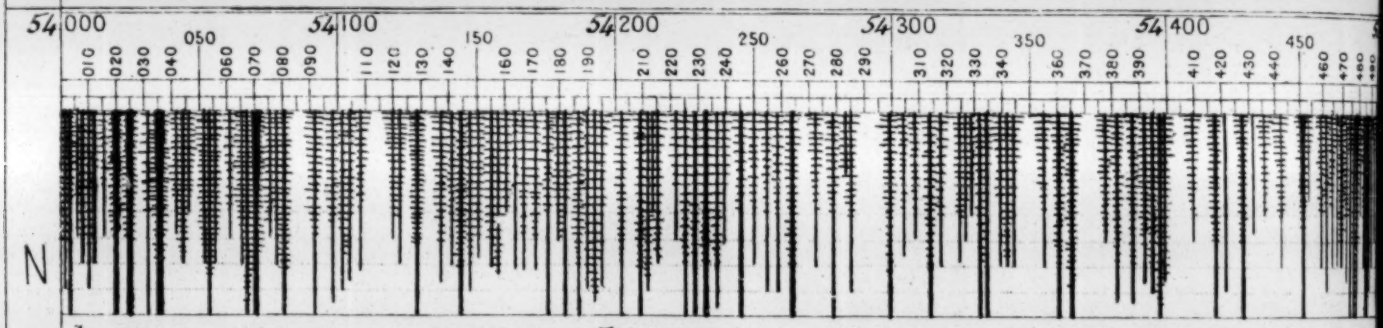
T H del 2

N IN VAC-U



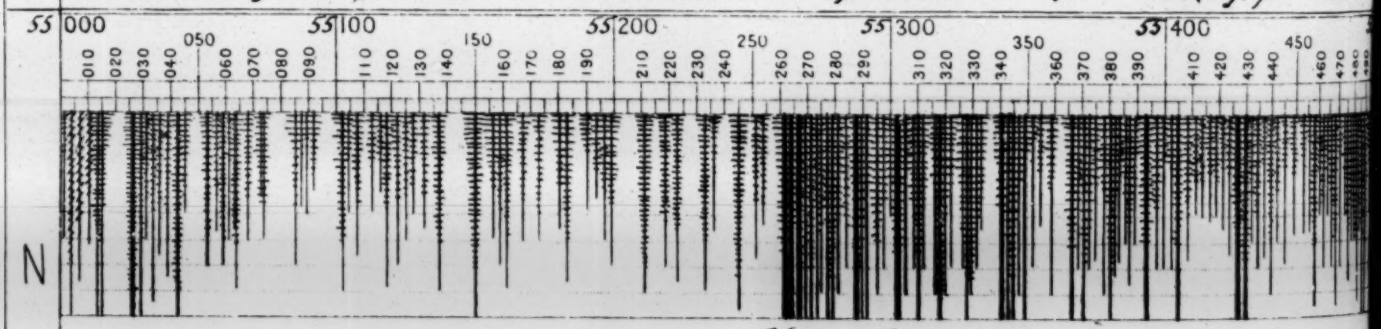
The broad Blue - band's lines losing in Intensity and Definition

☾ March 10 Cont^d and Concluded.



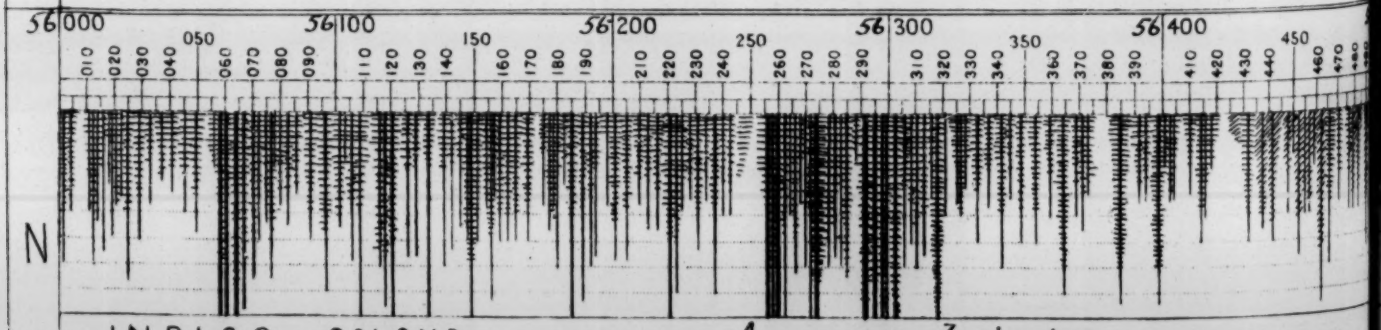
beginning intruding on a Broad band.

4 February 14, 1884. Prismatic Dispersion = 48° Mag. p. = 36.



Narrow beginning.

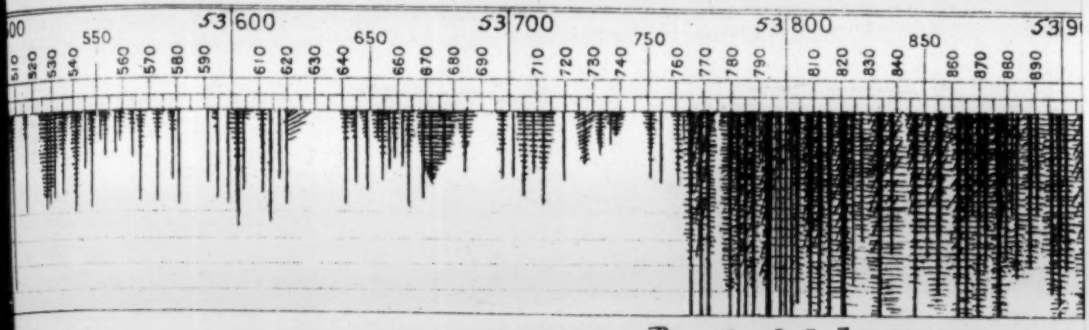
4 February 14, 1884. (Continued) A different order intruding.



INDIGO COLOUR. A narrow beginning.

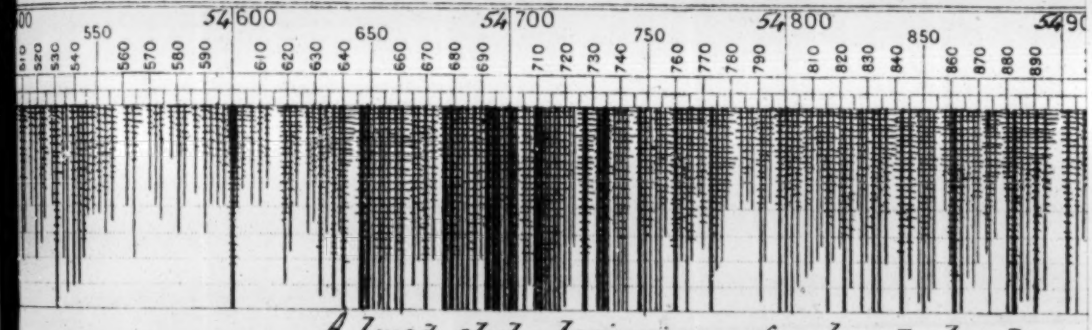
4 14th February 1884, (Continued.)

C-UUM - TUBES



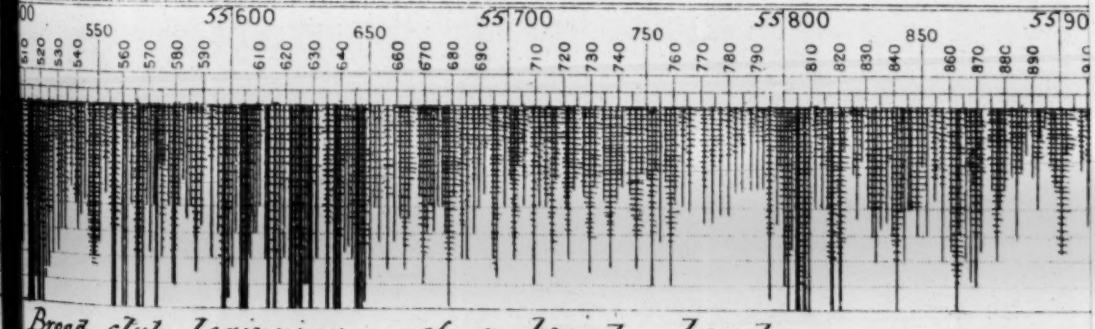
Broad club beginning.

2 Feb. 14, 1884.



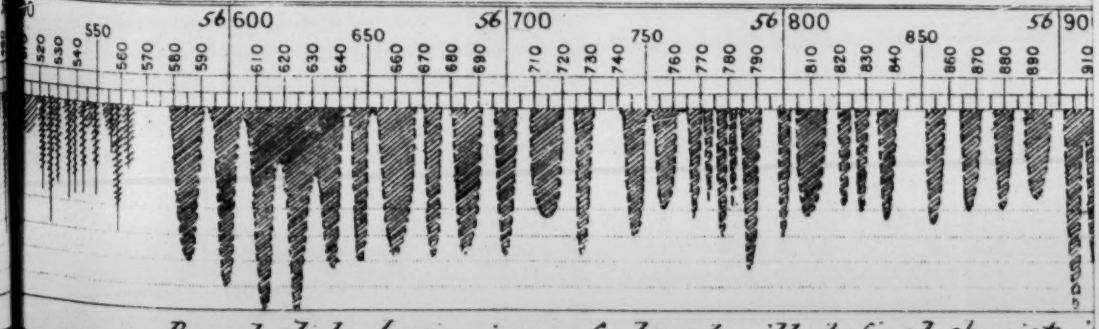
A broad club beginning, of a broad band.

BLUE COLOUR.



Broad club beginning, of a broad band.

INDIGO COLOUR.

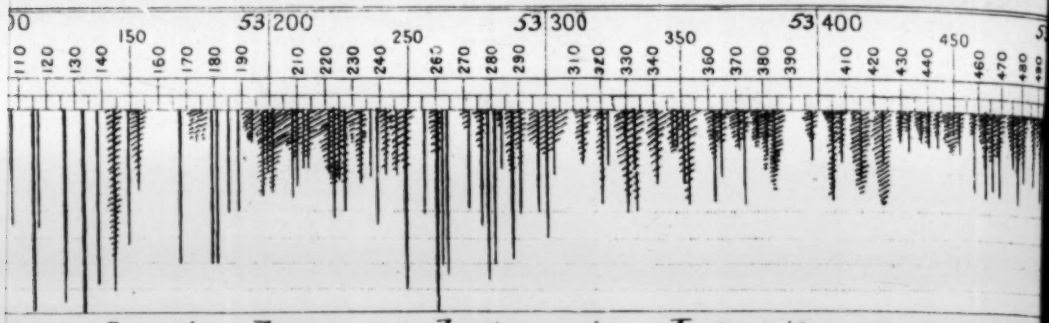


Broad club beginning of broad, ill defined characteri

2 February 21, 1884. Casella's 0.5 Press. N tube.

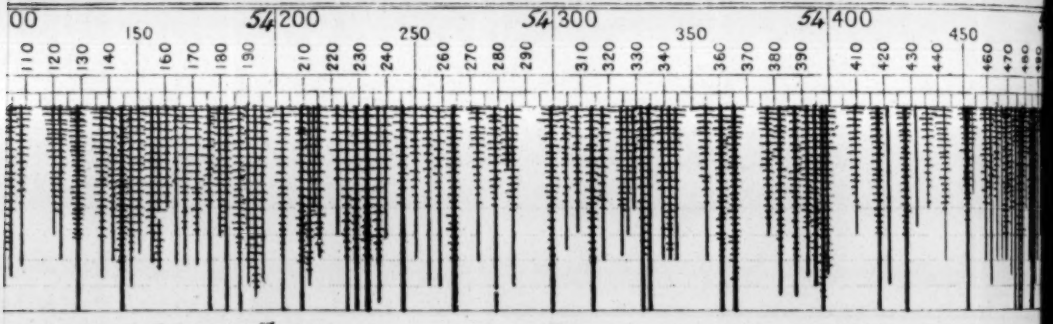
Photo-lith. 1884.

N IN VAC-U



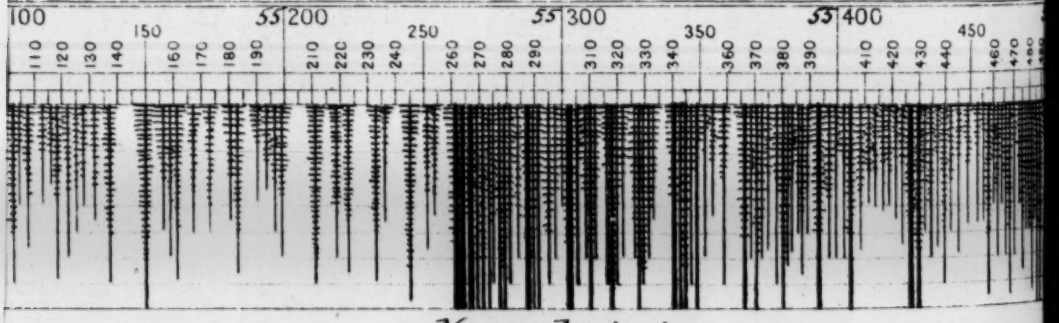
lue - band's lines losing in Intensity and Definitio

Cont^d and Concluded.



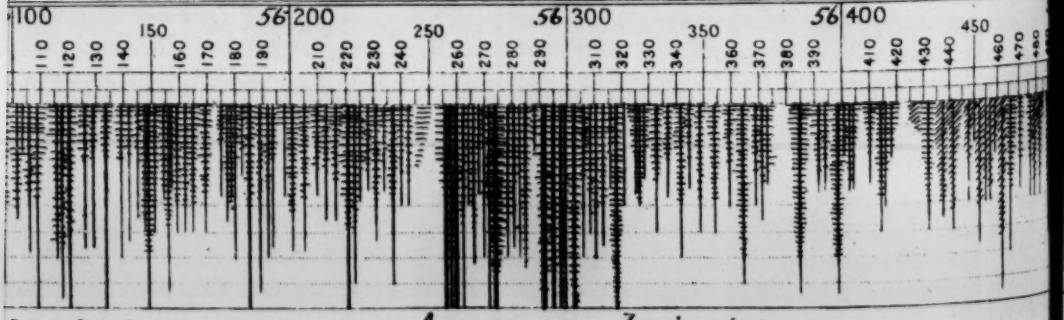
g on a Broad band.

, 1884. Prismatic Dispersion = 48° Mag. p. = 36.



Narrow beginning.

1884. (Continued) A different order intruding.

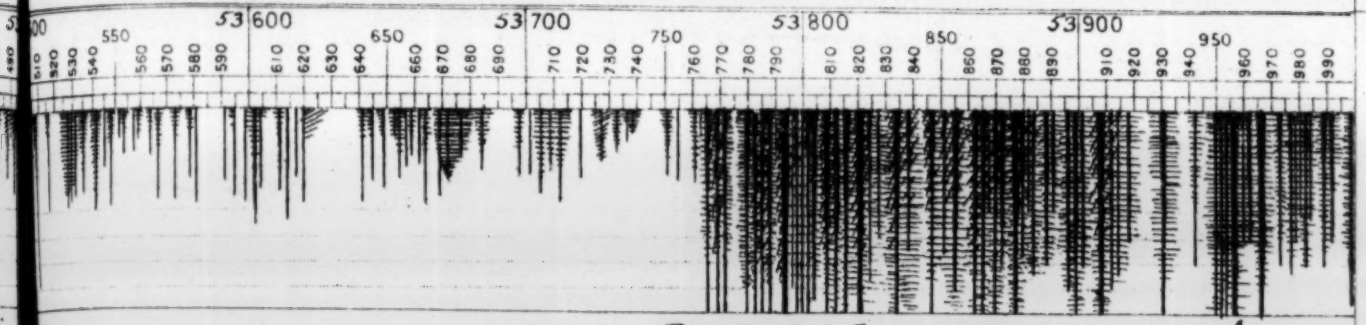


COLOUR. A narrow beginning.

ary 1884, (Continued.)

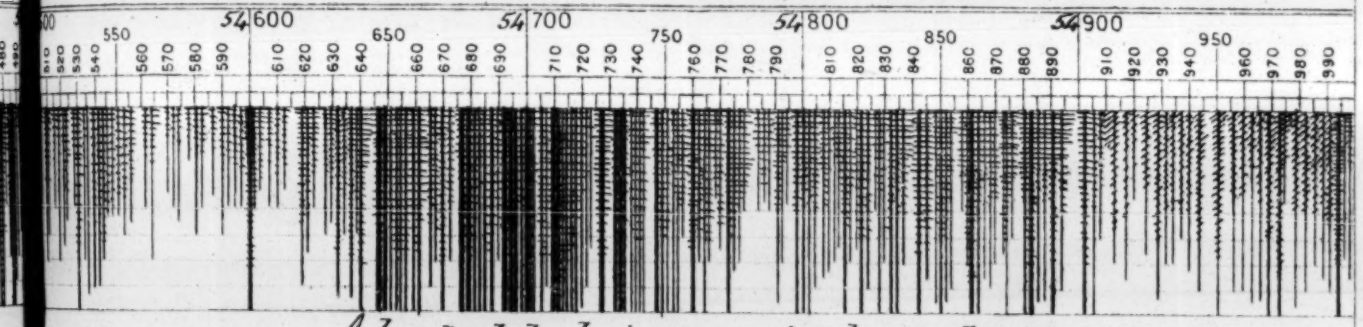
A. Ritchie & Son, Photo-Lith.

UUM - TUBES



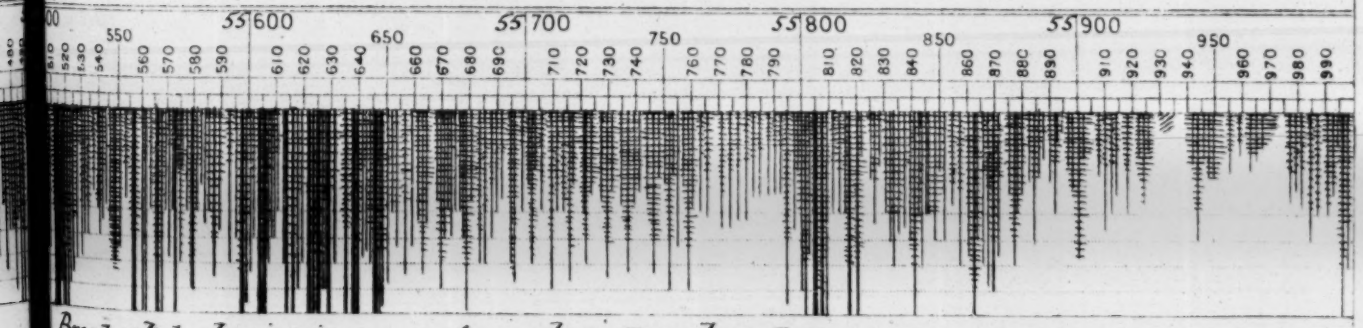
Broad club beginning. A narrow

2 Feb. 14, 1884.



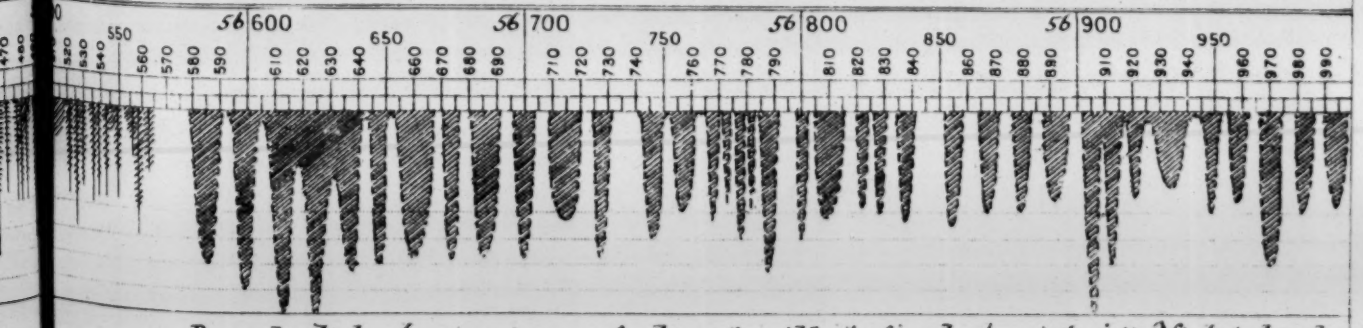
A broad club beginning, of a broad band.

BLUE COLOUR.



Broad club beginning, of a broad band.

INDIGO COLOUR.



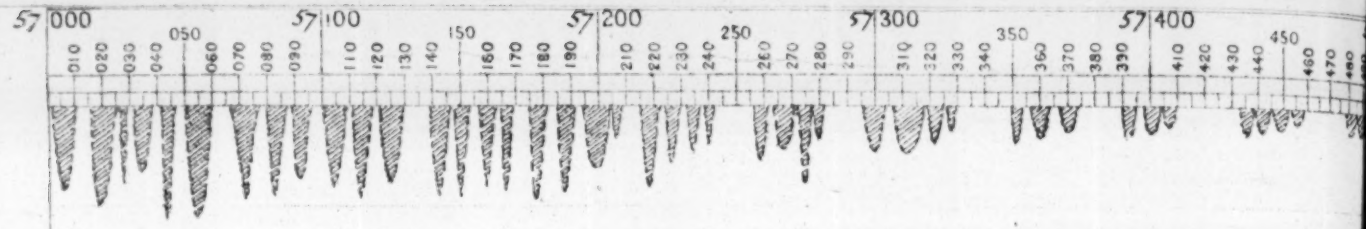
Broad club beginning of broad, ill defined characteristic Violet band.

4 February 21. 1884. Casella's 0.5 Press. N tube.

Photo-lith. 1884

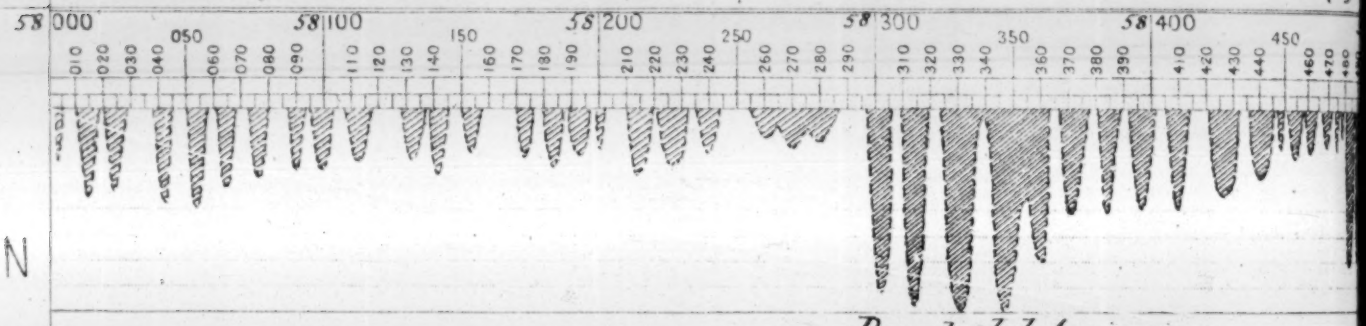
T H del 2.

N IN VAC



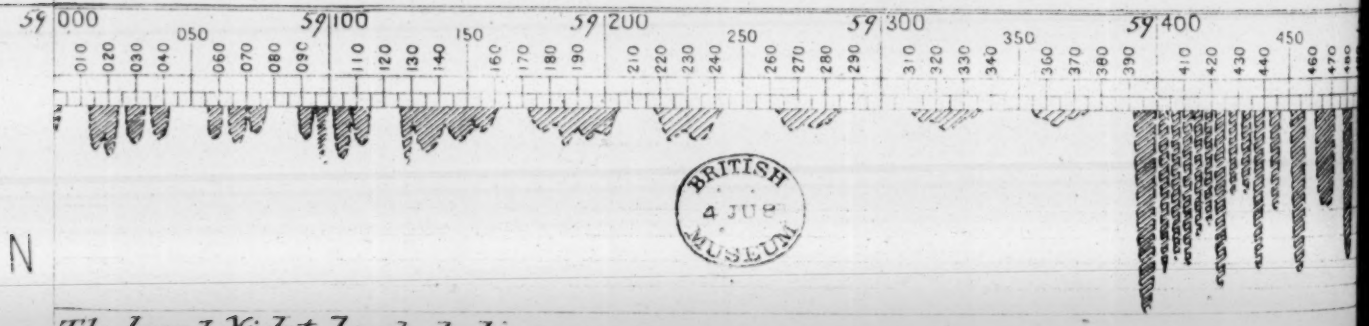
The broad Violet band paling.

4 February 21, 1884. Prismatic Dispersion = 36° A to H. Mag



Broad club beginning.

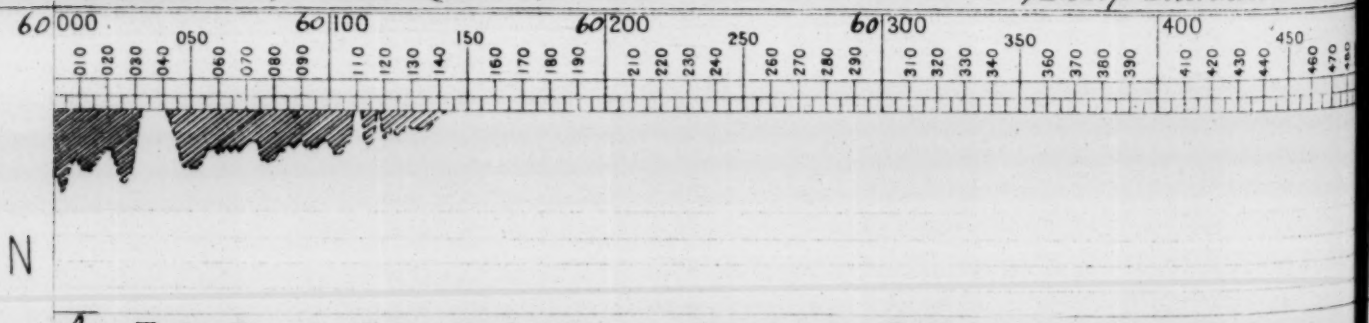
4 Febr. 21, 1884, (Cont.d) VIOLET.



BRITISH
4 JUE
MUSEUM

The broad Violet band paling.

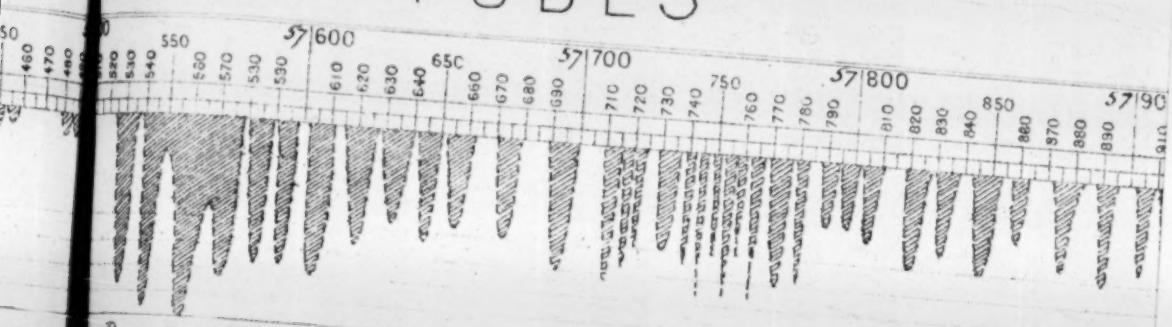
4 Febr. 21, 1884 (Cont.d)



An Intruder — but definition getting too bad.

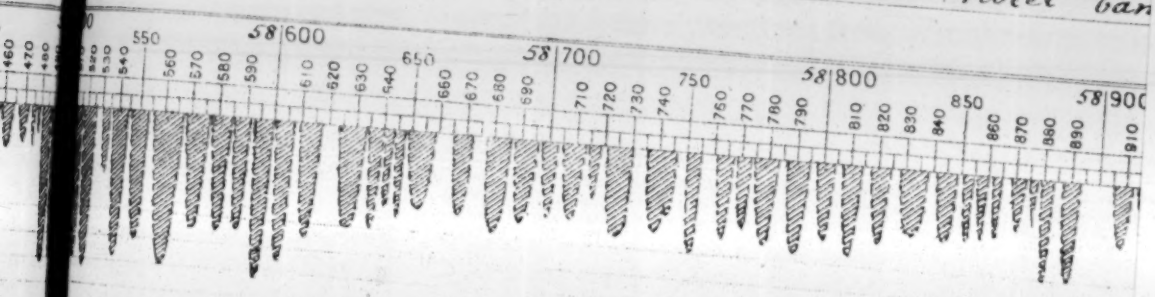
4 Febr. 21, 1884, (Cont.d).

C-UUM - TUBES

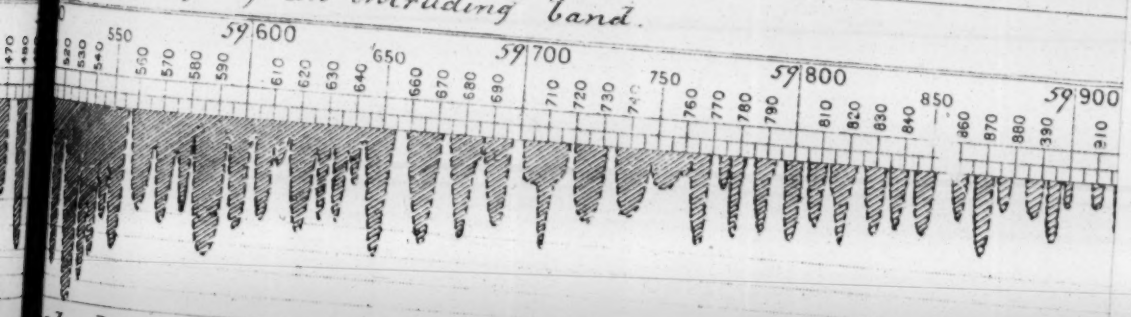


Broad club beginning of broad ill-defined Violet ban

Mag = 21.



Sh r beginning of an intruding band.



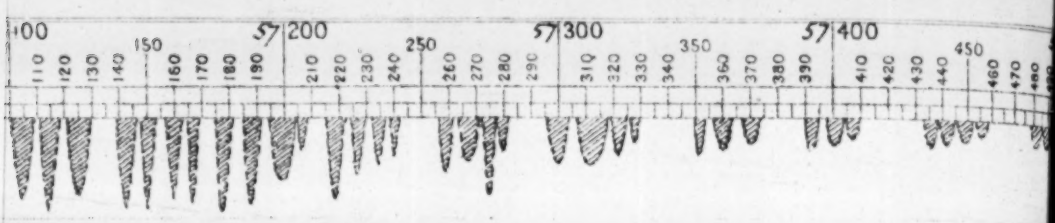
ad club beginning, of grandly broad Violet band.

d Tubes, after all the broad bands have disappeared.



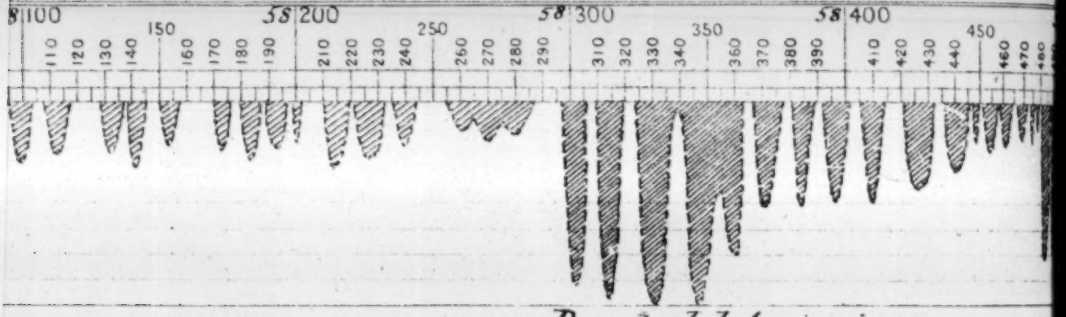
te-lith. 1884.

N IN VAC-U



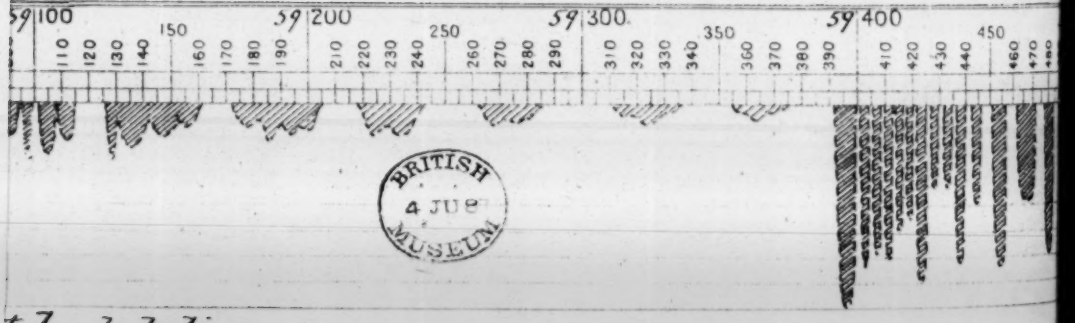
ct band paling.

1, 1884. Prismatic Dispersion = 36° A to H. Mag = 21.



Broad club beginning.

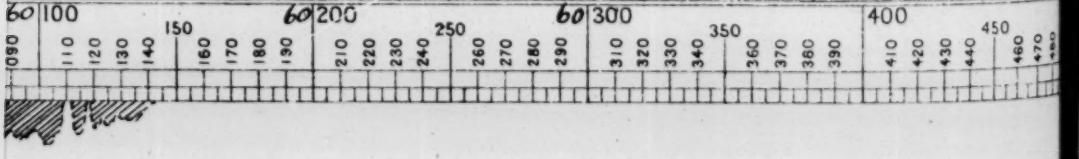
884, (Cont^d) VIOLET.



BRITISH 4 JUE MUSEUM

t band paling.

1884 (Cont^d) Sharp Intruder: lives

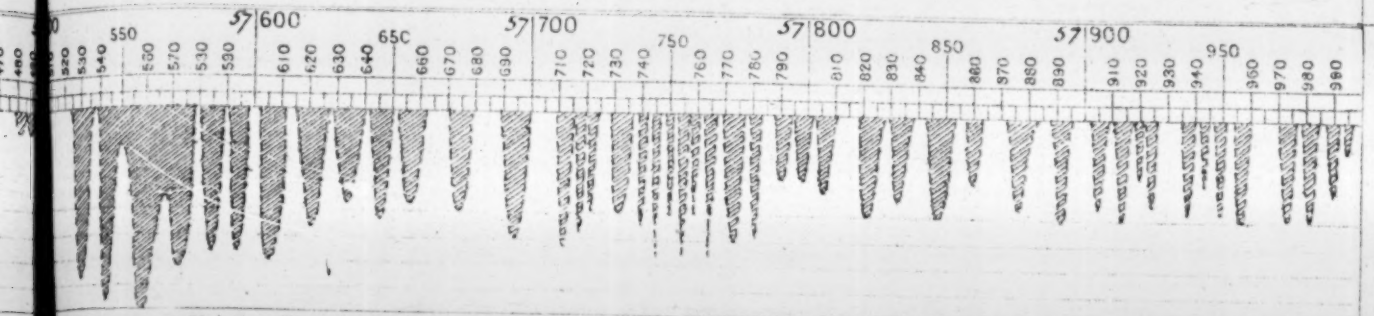


— but definition getting too bad.

1884, (Cont^d).

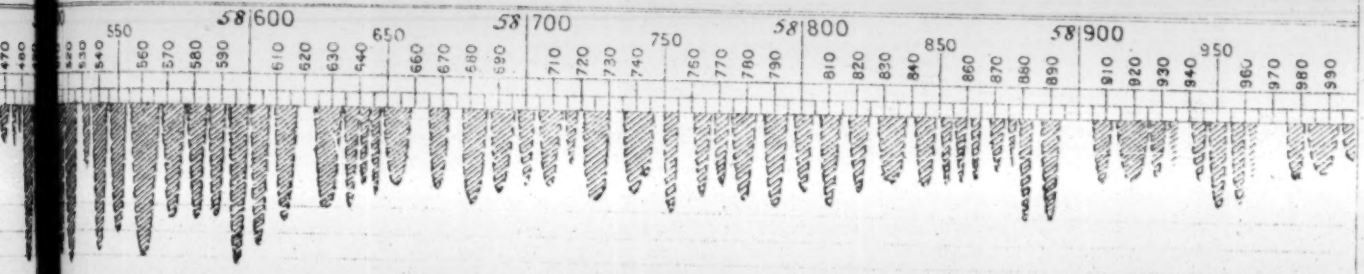
A. Ritchie & Son.

C-UUM - TUBES

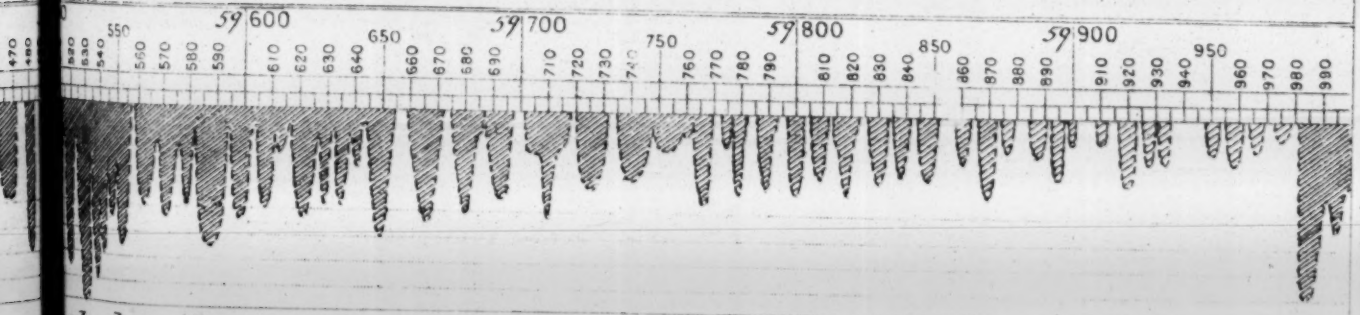


Broad club beginning of broad ill-defined Violet band.

Mag. = 21.

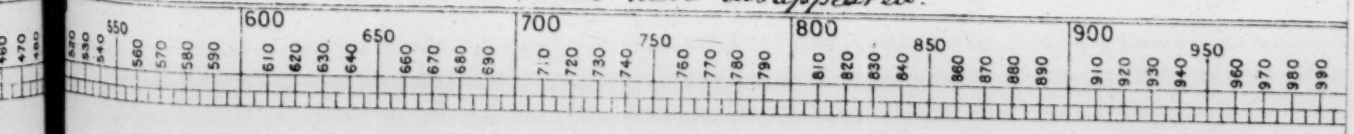


Sh[ar]p beginning of an intruding band.



Broad club beginning, of grandly broad Violet band.

Old Tubes, after all the broad bands have disappeared.



N

N

N

N

T. H. del. 2.

[illegible] & Son. [illegible]-Lith. 1884.

LIST OF ALL THE PLATES CONTAINED HEREIN,

VIZ. 29 DOUBLE-PAGE PLATES, AND 2 LONG FOLDING PLATES, AS BELOW.

R. S. E.'S VOLUME NUMBER.	THIS PAPER'S NUMBER.	GENERAL SUBJECT.	PARTICULAR DETAILS.
XLVIII.	1	**CH** IN BLOW-PIPE FLAME; *on a 40 foot Spectrum length.*	*Orange band, and Citron band.*
XLIX.	2		*Citron band continued, and Green band.*
L.	3		*Green band continued, and Blue band.*
LI.	4		*Violet band at the end thereof.*
LII.	5	*Characteristics of several methods of Gaseous-Incandescence. A single-page Representation.*	
LIII.	6	**CH** *again, but in Vacuum Tubes, and by Electric Spark.*	*Citron band and Green band.*
LIV.	7		*Green, Blue, Violet and Marsh Vi. bands.*
LV.	8	**CO,** *in Vacuum Tubes, on the same 40 foot Spectrum length.*	*Red band and Scarlet band.*
LVI.	9		*Orange band and Yellow band.*
LVII.	10		*Yellow band and Citron band.*
LVIII.	11		*Green band and Blue band.*
LIX.	12		*Indigo band and Violet band.*
LX.	13	**H,** *in Vacuum Tubes, on same Scale.*	*Early Red, Red, and Scarlet, regions.*
LXI.	14		*Orange, Yellow and Citron regions.*
LXII.	15		*Citron to Green, region.*
LXIII.	16		*Green, Glaucous, and Blue regions.*
LXIV.	17		*Blue and Indigo regions.*
LXV.	18		*Violet region.*
LXVI.	19	**O,** *in Vacuum Tubes, on same Scale.*	*Ultra Red, Red and Scarlet regions.*
LXVII.	20		*Orange and Yellow regions.*
LXVIII.	21		*Citron to Green, region.*
LXIX.	22		*Glaucous to Violet, region. N.B.—The Glaucous-coloured Oxygen triplets at 50,630 and 51,160 W.N. Pl. respectively, should be decreased somewhat in intensity and size.*
LXX.	23	**N,** *in Vacuum Tubes, on same Scale.*	*Ultra Red region.*
LXXI.	24		*Red and Scarlet, regions.*
LXXII.	25		*Yellow and Citron, regions.*
LXXIII.	26		*Citron and Green, regions.*
LXIV.	27		*Glaucous and Blue, regions.*
LXV.	28		*Blue and Indigo, regions.*
LXVI.	29		*Violet regions.*
LXXVII.	30	*Long, folding, Index Map, on a very small Spectrum scale, of all the above, and some other, Gases, at both high, and low, Electric temperatures; intended to serve as a Frontispiece and useful Key to the whole.*	
LXXVIII.	31	*Long, folding Plate of Green CO's extra CH's green, portion. Full size of original instrumental record, viz. on a 120 foot Spectrum length (A to H of Fraunhofer); with explication of its remarkable double Arithmetical Series of construction, by Professor Alex. S. Herschel, M.A., College of Science, Newcastle-on-Tyne.*	

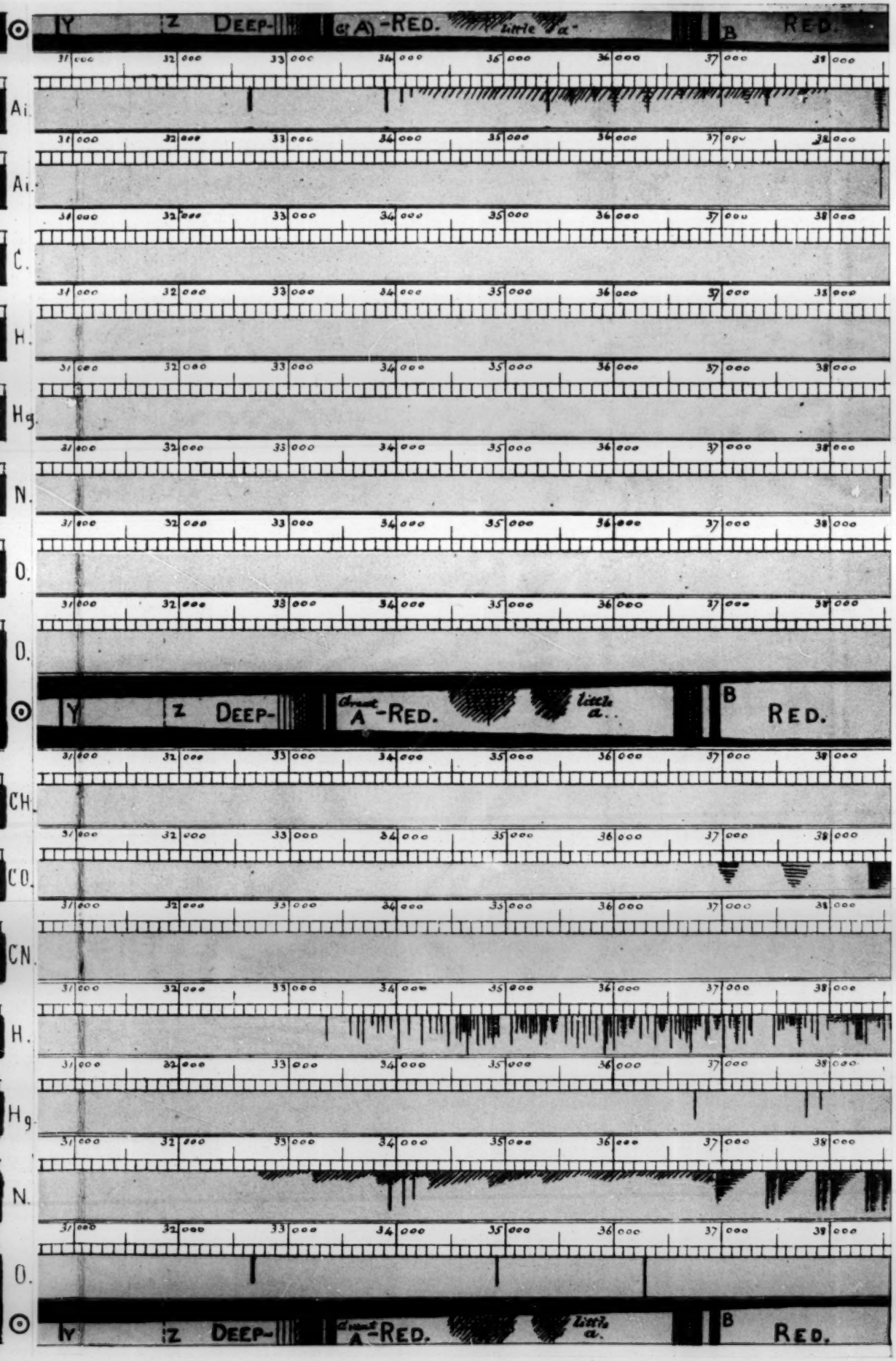
PLATE LXXVII.
OR 30
TRANSACTIONS R.S.E.
VOL. XXXII.

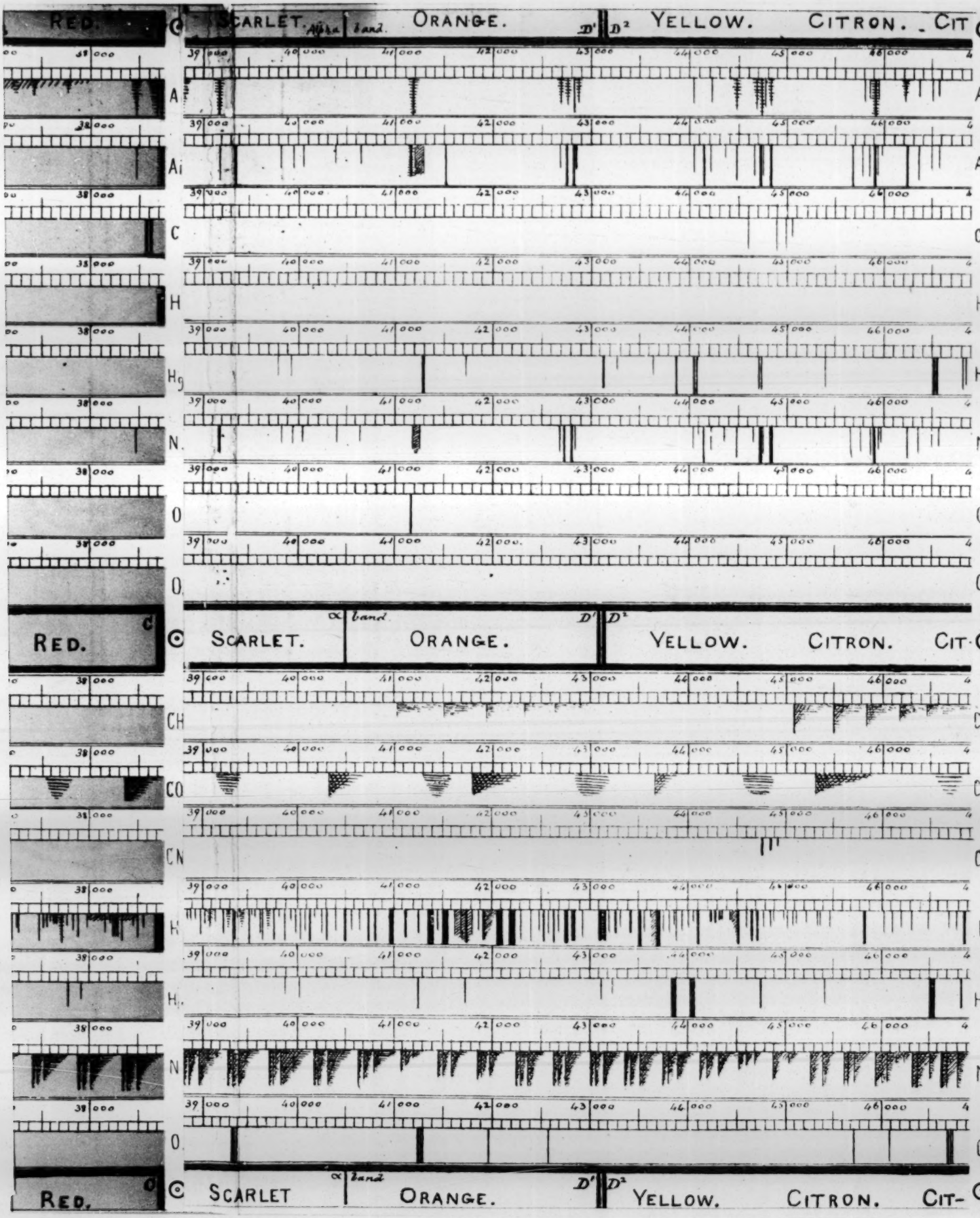
INDEX MAP OF THE GASEOUS SPECTRA,

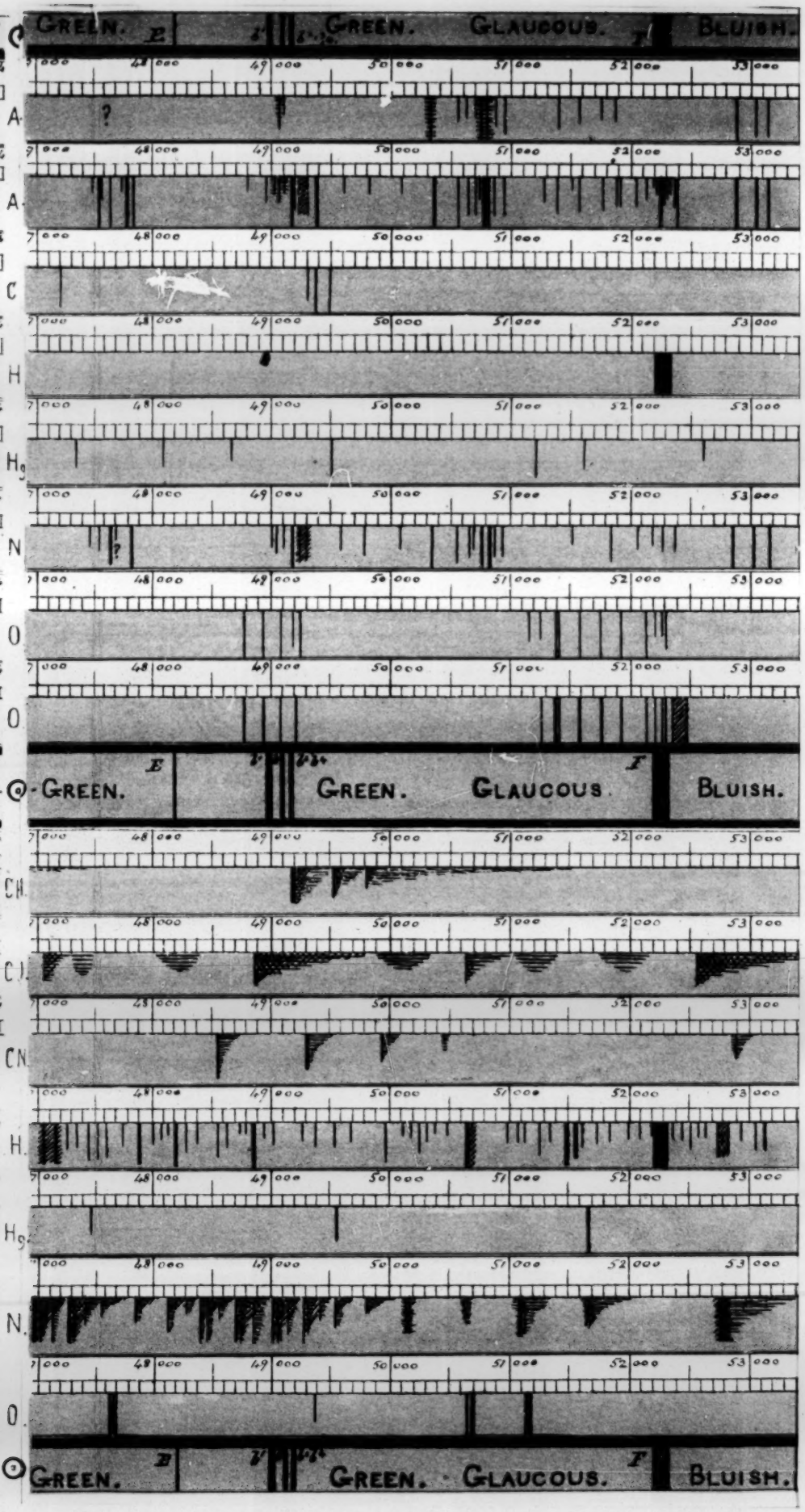
(AND A FEW OTHERS ALLIED TO THEM)

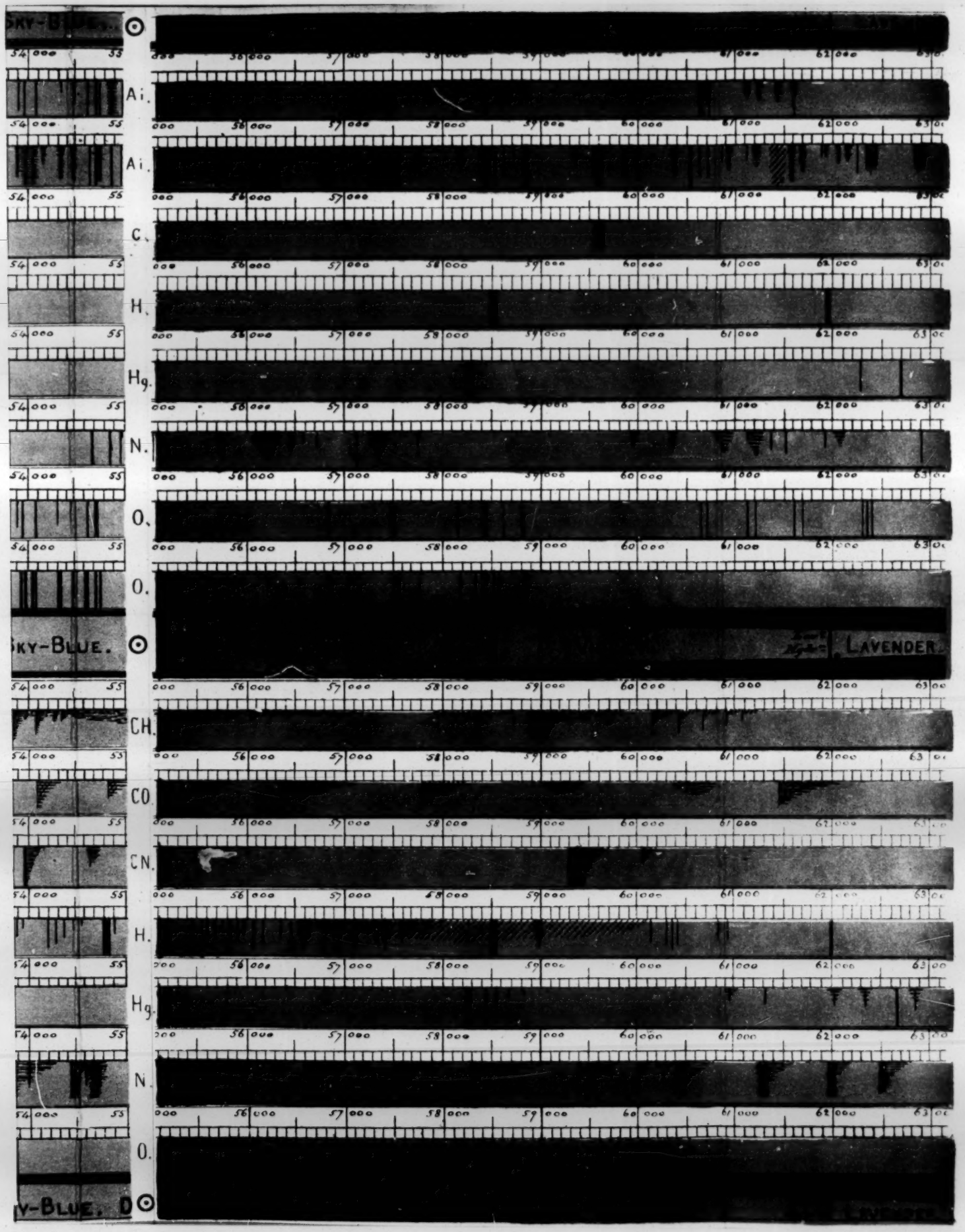
DISCUSSED BY THE MICROMETRIC MEASURES CONTAINED IN THIS PAPER, EXPRESSED IN W.N. *per* BRIT. INCH.

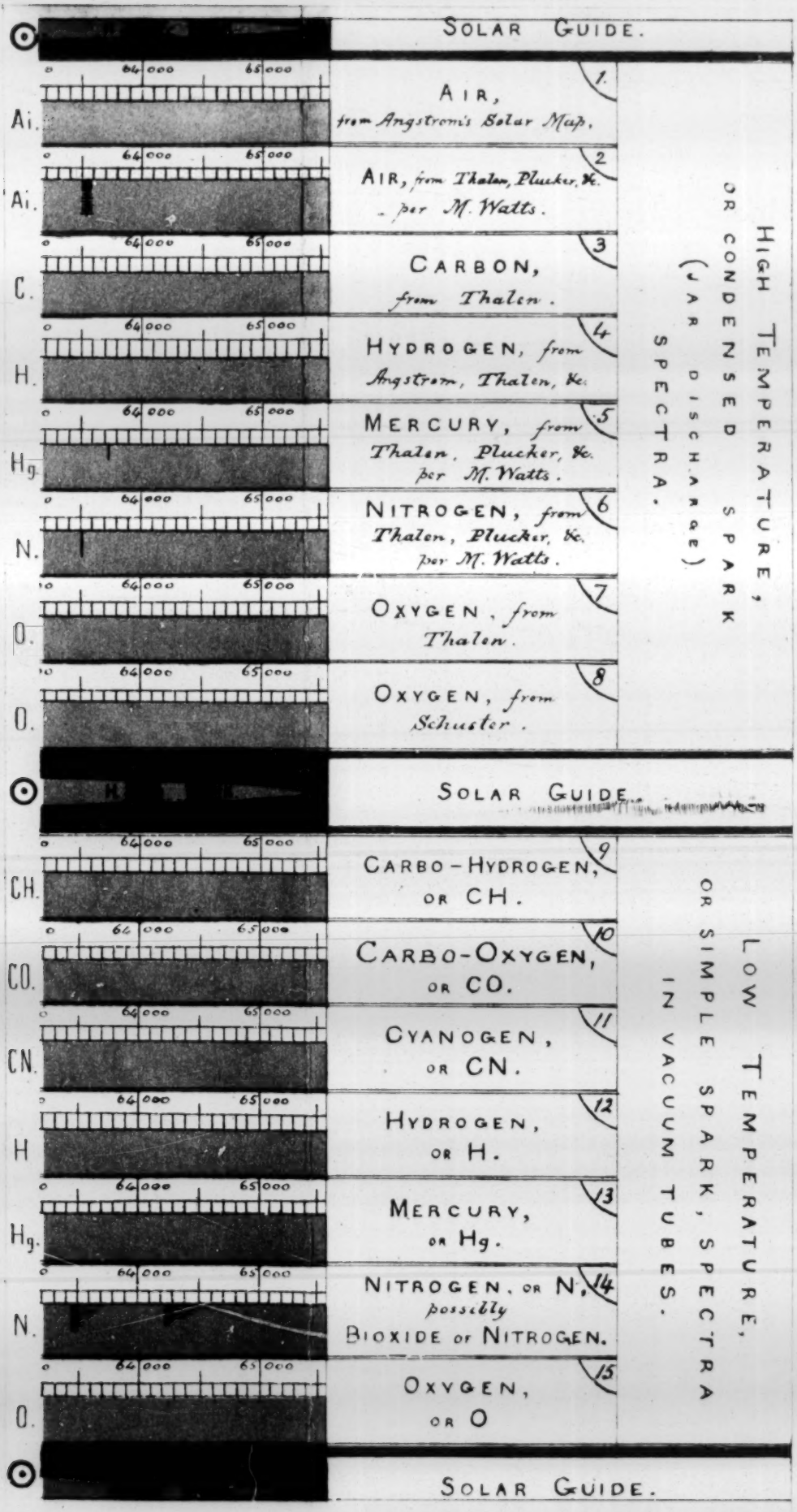



Y
Z DEEP-
(or A) -RED.
little a
B RED.
Ai.
Ai.
C.
H.
Hg.
N.
O.
O.
Y
Z DEEP-
almost A -RED.
little a.
B RED.
CH.
CO.
CN.
H.
Hg.
N.
O.
Y
Z DEEP-
almost A -RED.
little a.
B RED.


RED.
SCARLET.
Alpha band.
ORANGE.
D'
D²
YELLOW.
CITRON.
CIT
A
Ai
C
H
Hg
N.
O
O.
α band
CH
CO
CN
H
H.
Hg.
N
N.
O
O.
39 000
40 000
41 000
42 000
43 000
44 000
45 000
46 000


GREEN.
GREEN.
GLAUCOUS.
BLUISH.
A
A
C
H
H2
N
O
O
GREEN.
GREEN.
GLAUCOUS.
BLUISH.
CH
CI
CN
H
H2
N
O
GREEN.
GREEN.
GLAUCOUS.
BLUISH.


Ai.
Ai.
C.
H.
Hg.
N.
O.
O.
LAVENDER.
CH.
CO.
CN.
H.
Hg.
N.
O.


Solar Guide.
64 000
65 000
Ai.
Air, from Angstrom's Solar Map. 1.
Ai.
Air, from Thalen, Plucker, &c. per M. Watts. 2
C.
Carbon, from Thalen. 3
H.
Hydrogen, from Angstrom, Thalen, &c. 4
Hg.
Mercury, from Thalen, Plucker, &c. per M. Watts. 5
N.
Nitrogen, from Thalen, Plucker, &c. per M. Watts. 6
O.
Oxygen, from Thalen. 7
O.
Oxygen, from Schuster. 8
High Temperature, or condensed spark (jar discharge) spectra.
Solar Guide.
CH.
Carbo-Hydrogen, or CH. 9
CO.
Carbo-Oxygen, or CO. 10
CN.
Cyanogen, or CN. 11
H
Hydrogen, or H. 12
Hg.
Mercury, or Hg. 13
N.
Nitrogen, or N. possibly Bioxide of Nitrogen. 14
O.
Oxygen, or O 15
Low Temperature, or simple spark, spectra in vacuum tubes.
Solar Guide.

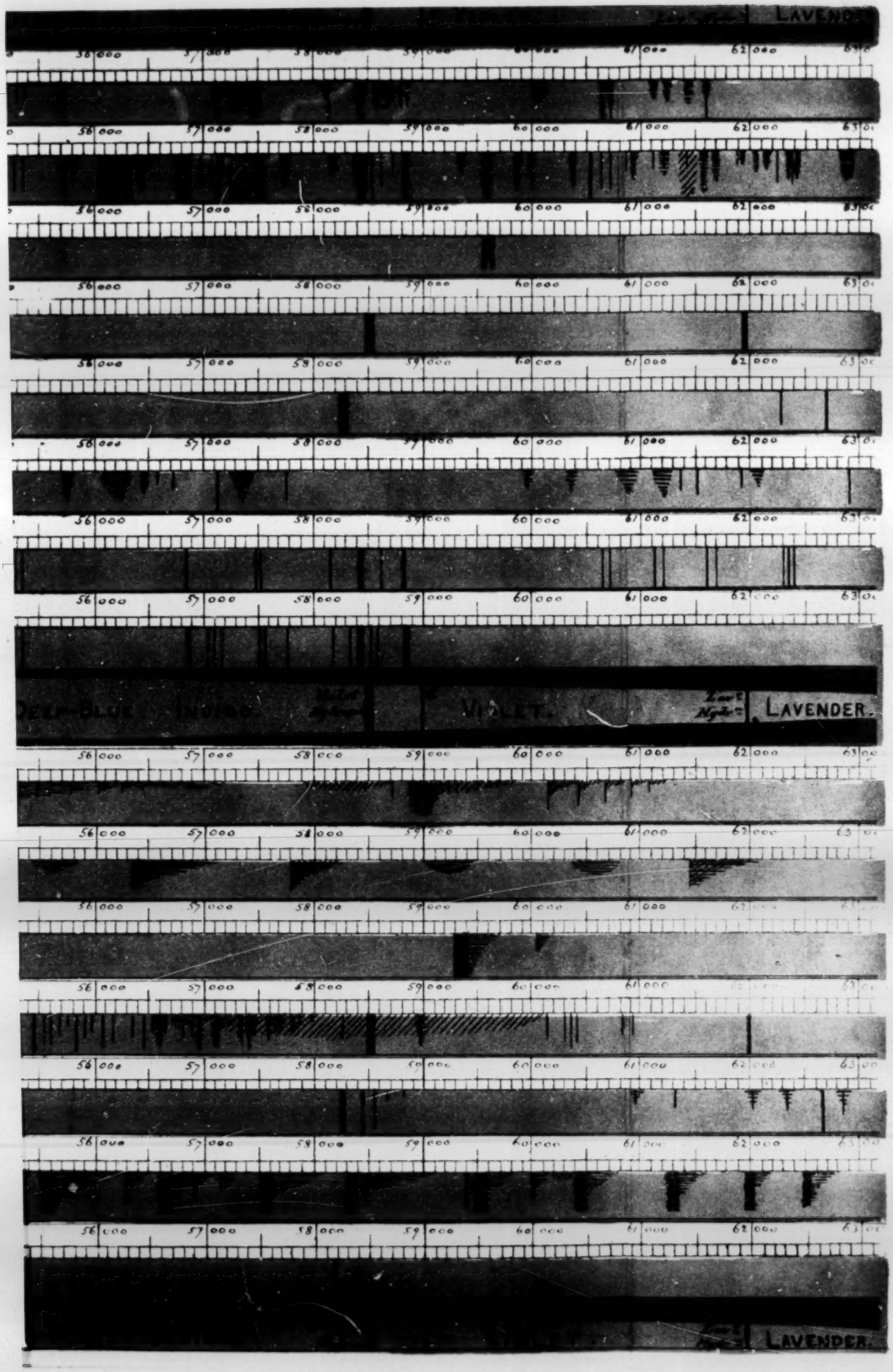

LAVEND
Ai.
Ai.
C.
H.
Hg.
N.
O.
O.
DEEP-BLUE
VIOLET
LAVENDER
CH.
CO.
CN.
H
Hg.
N.
O.
LAVENDER

PLATE LXXVII.
OR 30
TRANSACTIONS R.S.E.
VOL. XXXII.

INDEX MAP OF THE GASEOUS SPECTRA,

(AND A FEW OTHERS ALLIED TO THEM)

DISCUSSED BY THE MICROMETRIC MEASURES

CONTAINED IN THIS PAPER, EXPRESSED IN W.N. *per* BRIT. INCH.

PLATE LXXVIII.
OR 31.
TRANSACTIONS R.S.E.
VOL. XXXII.

THE GREEN CO BAND'S BEGINNING, ON THE SCALE · FOR SIZE EM
THEIR "MESURES MICROMÉTRIQUES" 1
POSITIVE, TO THE NEGATIVE, MANNER

THE SAME GREEN CO BAND'S BEGINNING
EXPLICATED AS T

THEORETICAL ARITHM. PROGRESSION,
1+2+3+4+5+6+7+8+9+10+11+12+13+14+15+16+17+ &c.

SPLIT-LINE SPECTRUM PRODUCED UPWARDS.

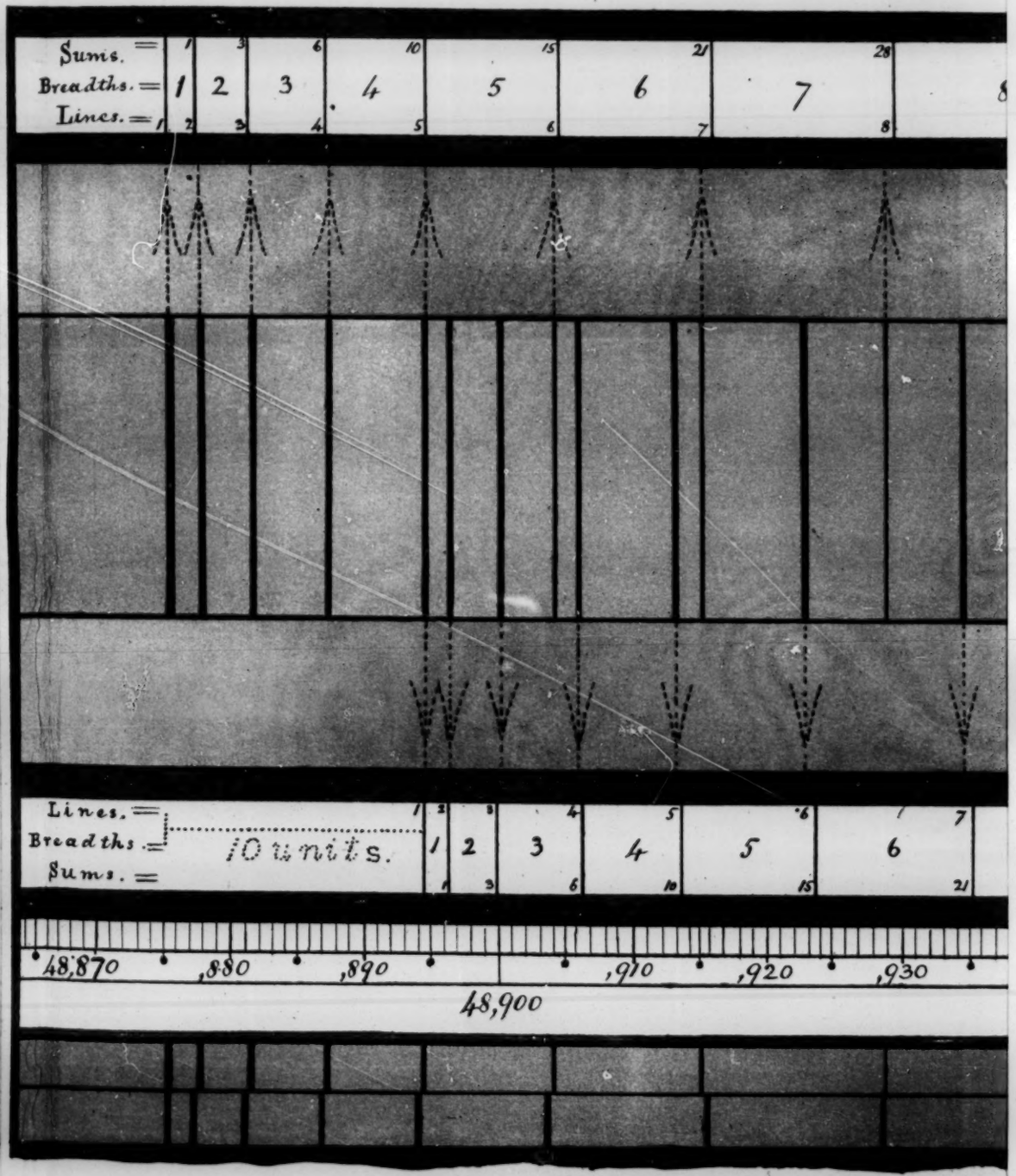
OBSERVATIONAL,
VIZ. EVERY LINE, ⟶
IN NEGATIVE REPRESENTATION
EXACTLY AS MEASURED,
FULL SIZE OF THE INSTRUMENTAL RECORD.

MAIN-LINE SPECTRUM PRODUCED DOWNWARDS.

THEORETICAL ARITHM. PROGRESSION AGAIN,
BEGINNING ON 5th LINE OF FIRST SERIES.

SPECTRUM-PLACE IN WAVE-NUMBER PER BR. INCH,
APPROXIMATELY ONLY:

COMPARISON OF *C.P.S. obs.ᵗ del.ᵗ* { SPLIT-LINE SPECTRUM, WITH / MAIN-LINE SPECTRUM SET *10* UNITS' BACK.

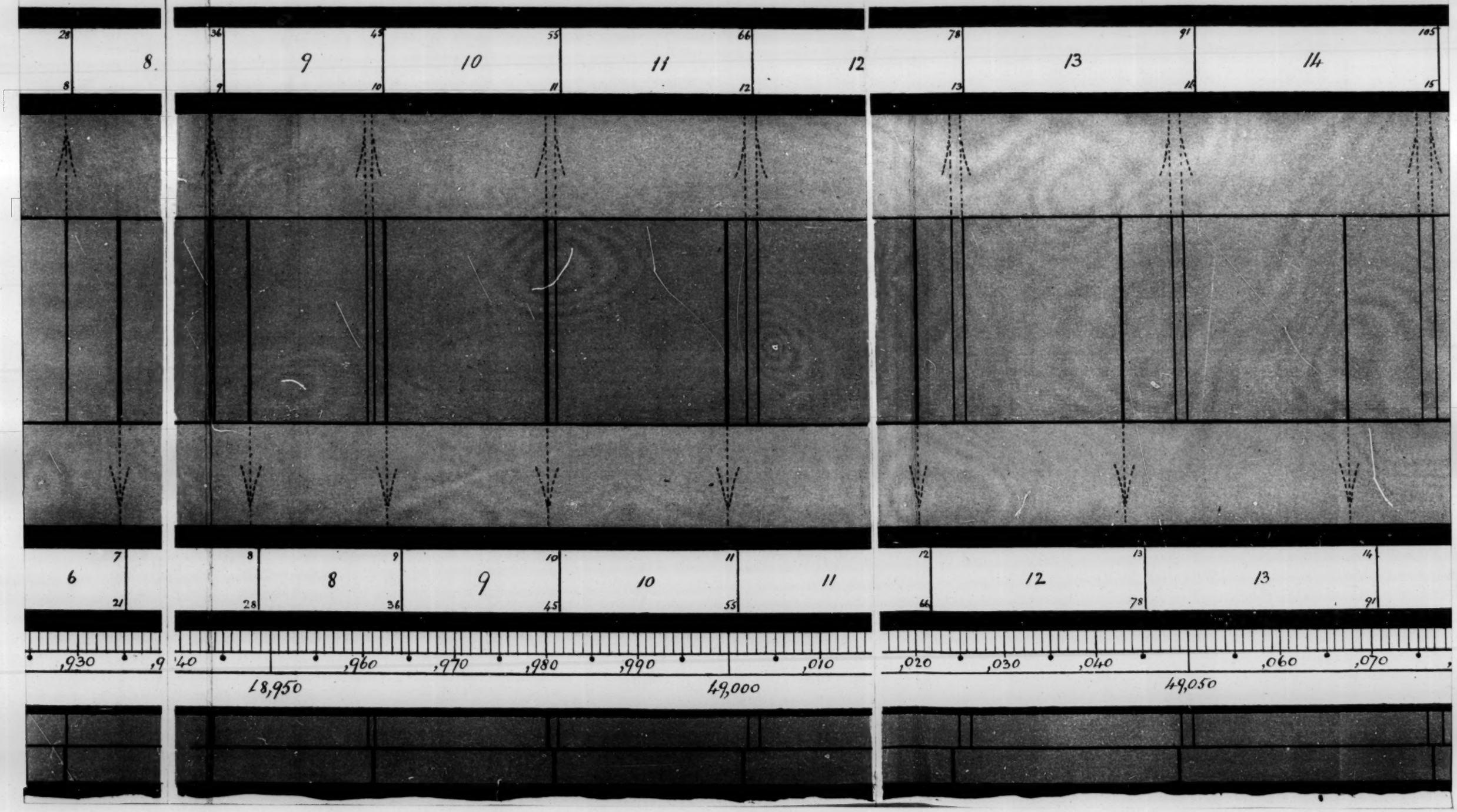


SIZE EMPLOYED BY M. M. ANGSTROM AND THALEN, IN
IQUES" 1875; BUT TRANSLATED HERE FROM THE
, MANNER, AS REGARDS LIGHT AND SHADE.



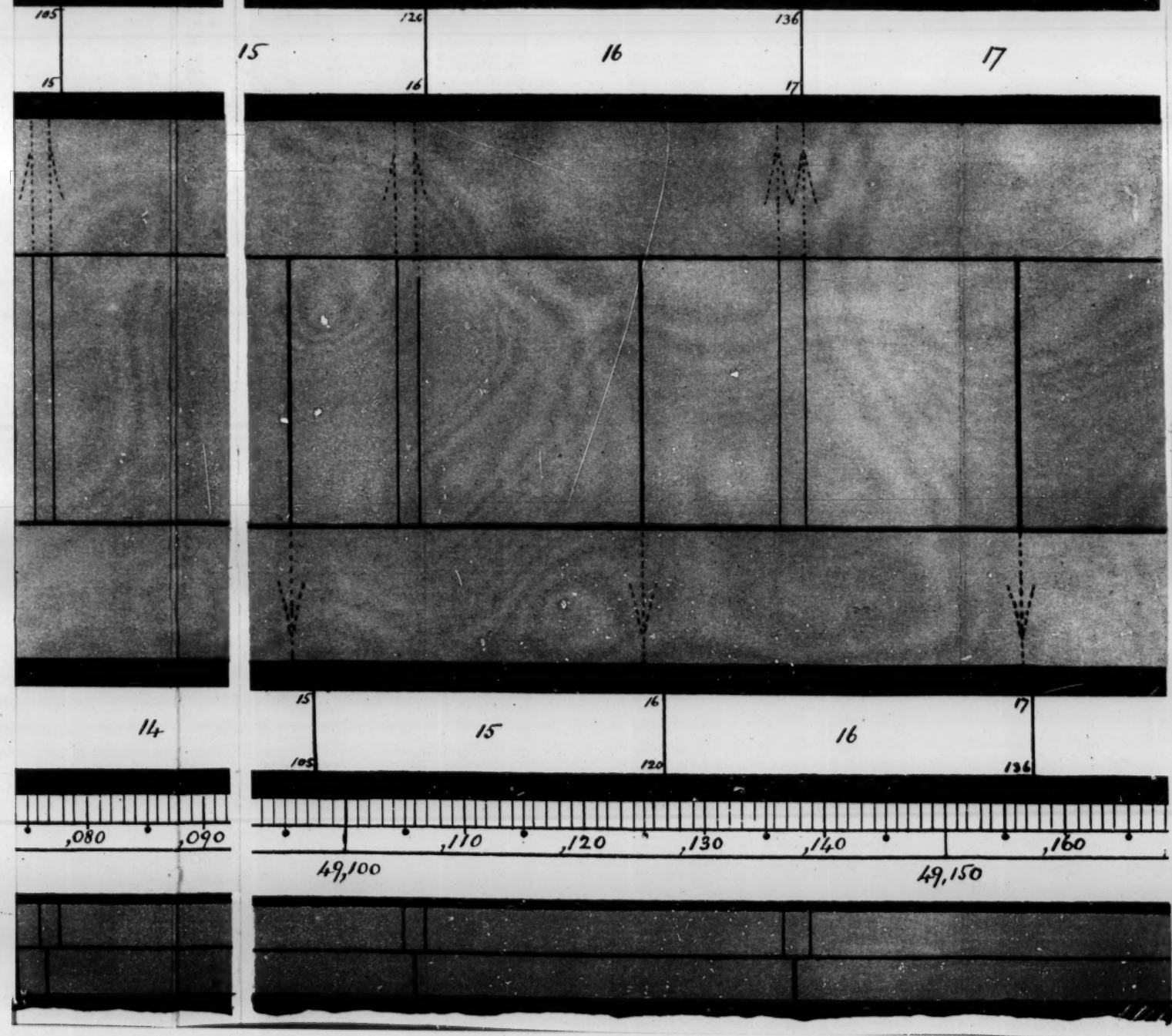
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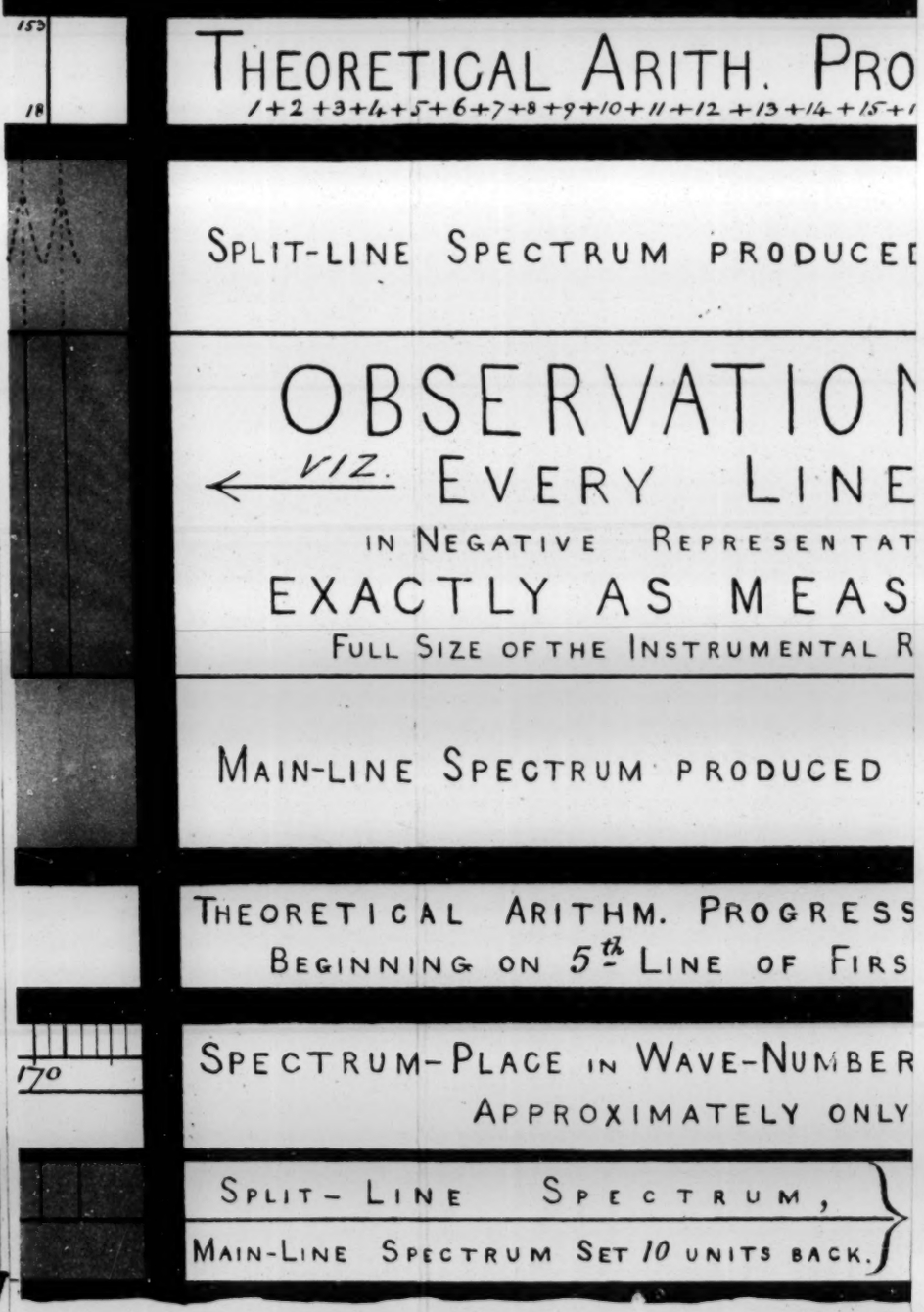
INNING, RESOLVED IN EDINBURGH BY C. PIAZZI SMYTH INTO ITS
ED AS TWO SERIES IN ARITHMETICAL PROGRESSION BY PROFESSOR ALEXANDE



herches sur les Spectres des Métalloïdes, par A. J. Angström et T. R. Thalén,
(Extrait des Nova Acta Reg. Soc. Upsal. Ser. III, Vol. IX.)
Upsal, Ed. Berling, Imprimeur de l'Université. 1875.

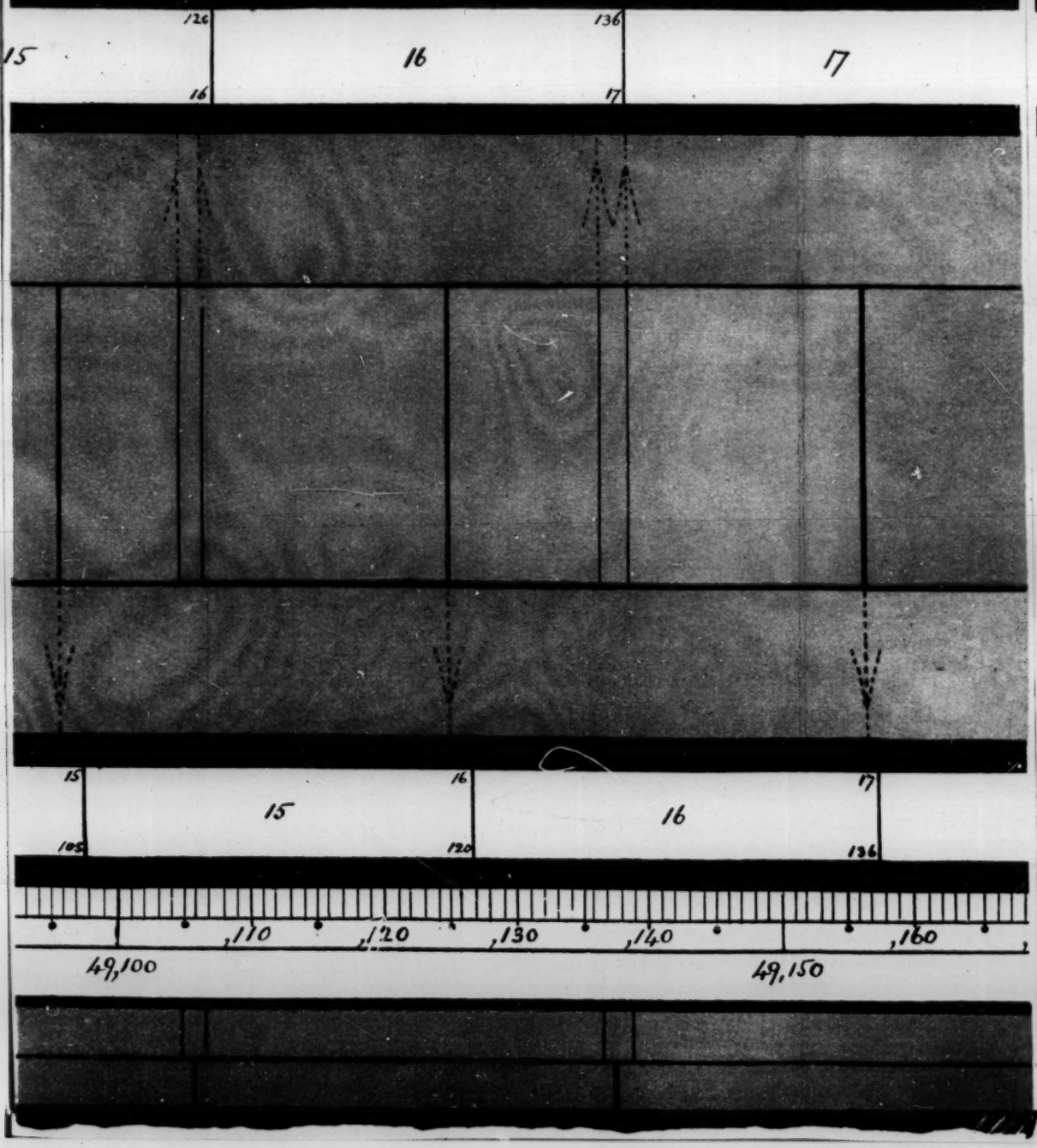
; COMPONENT LINES, AND THESE
NDER S. HERSCHEL, Novr 1883.





es Spectres des Métalloïdes, par A. J. Angström et T. R. Thalén,
rait des Nova Acta Reg. Soc. Upsal. Ser. III, Vol. IX.)
sal, Ed. Berling, Imprimeur de l'Université. 1875.

NENT LINES, AND THESE
ERSCHEL, Novr 1883.



THEORETICAL ARITH. PROGRESSION.
1+2+3+4+5+6+7+8+9+10+11+12+13+14+15+16+17+&c.

SPLIT-LINE SPECTRUM PRODUCED UPWARDS.

OBSERVATIONAL,

← viz. EVERY LINE,

IN NEGATIVE REPRESENTATION,

EXACTLY AS MEASURED,

FULL SIZE OF THE INSTRUMENTAL RECORD.

MAIN-LINE SPECTRUM PRODUCED DOWNWARDS.

THEORETICAL ARITHM. PROGRESSION AGAIN,
BEGINNING ON 5th LINE OF FIRST SERIES.

SPECTRUM-PLACE IN WAVE-NUMBER PER BR. INCH,
APPROXIMATELY ONLY.

SPLIT-LINE SPECTRUM,
MAIN-LINE SPECTRUM SET 10 UNITS BACK.
} COMPARED WITH T.H. del. 2.

XXV.—*On Bipartite Functions.* By Thomas Muir, LL.D.

(Read 16th February 1885.)

1. If a row of n elements be taken, and closely following this array, but separated by a bar from it, we write n rows of n elements each; and closely following either outside *column* of this square array, but separated by a bar from it, we write n *columns* of n elements each; and closely following an outside *row* of this second square array, but separated by a bar from it, we write n *rows* of n elements each; and so on, passing from the rows or columns of one array to the columns or rows of the next, and ending not with a square array, but, as we began, with a single line of elements, we have the matrix representation of a *bipartite function.*

For example, when $n=3$ and the number of square arrays is 4, the representation is

$$\begin{array}{ccc|ccc|ccc}
 & & & h_3 & k_3 & l_3 & r_1 & r_2 & r_3 \\
 & & & h_2 & k_2 & l_2 & n_1 & n_2 & n_3 \\
a_1 & a_2 & a_3 & h_1 & k_1 & l_1 & m_1 & m_2 & m_3 \\
\hline
b_1 & c_1 & d_1 & e_1 & e_2 & e_3 & x_1 & y_1 & z_1 \\
b_2 & c_2 & d_2 & f_1 & f_2 & f_3 & & & \\
b_3 & c_3 & d_3 & g_1 & g_2 & g_3 & & &
\end{array},$$

or

$$\begin{array}{ccc|ccc|ccc}
a_1 & a_2 & a_3 & & & & & & \\
\hline
b_1 & c_1 & d_1 & e_1 & e_2 & e_3 & & & \\
b_2 & c_2 & d_2 & f_1 & f_2 & f_3 & & & \\
b_3 & c_3 & d_3 & g_1 & g_2 & g_3 & & & \\
\hline
 & & & h_1 & k_1 & l_1 & m_1 & m_2 & m_3 \\
 & & & h_2 & k_2 & l_2 & n_1 & n_2 & n_3 \\
 & & & h_3 & k_3 & l_3 & r_1 & r_2 & r_3 \\
 & & & & & & x_1 & y_1 & z_1
\end{array}.$$

2. The ordinary algebraical expression of the function is obtained from the matrix representation by forming every possible term containing as a factor one, and only one, element from each array, subject to the condition that the element to be taken from any one array must be in the same row or column with the element taken from the preceding array, and in the same column or row with the element taken from the following array; and then connecting, by means of plus signs, the terms thus formed.

For example,

$$\begin{array}{cc|cc} a & b & & \\ c & d & g & i \\ e & f & h & j \\ \hline & & k & l \end{array} \equiv acgk+acil+aehk+aejl+bdgk+bdil+bfhk+bfjl;$$

and

$$\begin{array}{cccc} a & b & c & d \\ \hline e & f & g & h \end{array} \equiv ae+bf+cg+dh,$$
$$\equiv (a\ b\ c\ d \diagdown e\ f\ g\ h).$$

3. If the number of elements in a row or column be n, the bipartite is said to be of the nth order: if the number of arrays, square or not, be m, it is evidently of the mth degree; and combining these we may speak of such a bipartite as being of the deg-order (m, n).

4. The number of terms in the final expansion of a bipartite of deg-order (m, n) is n^{m-1}.

For the deg-order $(2, n)$ the number is evidently n, *i.e.*, n^{2-1}: for the deg-order $(3, n)$ there must be one term, and one only, for every element in the square array, and therefore in all n^2 terms, *i.e.*, n^{3-1}; and if the number of terms in a bipartite of deg-order (p, n) be n^{p-1}, it is readily made evident that the number in the bipartite of deg-order $(p+1, n)$ is n^p: hence the statement is established.

5. Each element of any one of the square arrays of a bipartite of deg-order (m, n) occurs $n^{m-1} \div n^2$, *i.e.*, n^{m-3} times in the final expansion; and each element of either of the other arrays occurs $n^{m-1} \div n$, *i.e.*, n^{m-2} times.

For, one of the former, and only one, must occur in each term, and there are n^2 of them; and one of the latter, and only one, must occur in each term, and there are n of them.

6. The elements of the square arrays may therefore be called *secondary* elements, and the others *primary*.

7. The two lines of primary elements may be distinguished as *initial* and *final*. Strictly speaking, however, either is at the beginning, and the other at the end; for the definition shows that the order of writing the arrays may be reversed without affecting the final expansion. Thus

$$\begin{array}{cc|cc} a & b & & \\ c & d & g & i \\ e & f & h & j \\ \hline & & k & l \end{array} \equiv \begin{array}{cc|cc} l & k & & \\ j & h & f & e \\ i & g & d & c \\ \hline & & b & a \end{array}.$$

8. Also, it may be remarked, the law of formation of the terms would give the same result if the initial row of any bipartite were made into a *column*, and at the same time all the other rows and columns altered accordingly. Thus the bipartite of § 7 may also be written

$$\begin{array}{c|cc|c} a & c & e & \\ b & d & f & \\ \hline & g & h & k \\ & i & j & l \end{array} \quad \text{or} \quad \begin{array}{cc|c} i & j & l \\ g & h & k \\ \hline a & c & e \\ b & d & f \end{array}$$

if on any occasion there be convenience in so doing.

9. If any two rows or two columns of a square array be interchanged, and, at the same time, the two collinear rows or columns in one of the adjacent arrays, the bipartite is in substance unaltered.

Thus

$$\begin{array}{cc|cc|c} & & m & n & q \\ a & b & k & l & p \\ \hline c & d & g & i & \\ e & f & h & j & \end{array} = \begin{array}{cc|cc|c} a & b & m & n & q \\ \hline e & f & h & j & \\ c & d & g & i & \end{array},$$

$$= \begin{array}{cc|cc|c} & & k & l & p \\ a & b & m & n & q \\ \hline c & d & g & i & \\ e & f & h & j & \end{array}, \quad \ldots\ldots$$

10. A bipartite is multiplied by any quantity if each of the elements of any one of its arrays be multiplied by that quantity.

11. A bipartite having every element of one of its square arrays a sum of p terms may be expressed as the sum of p bipartites, the first of which is got from the original by deleting all the terms of each of the p-termed elements except the first term, the second by deleting all the terms of each of the p-termed elements except the second term, and so on.

12. The cofactor of any one of the principal elements of a bipartite of deg-order (m, n) is expressible as a bipartite of deg-order $(m-1, n)$, which is obtained from the original bipartite by deleting, first, the line to which the said principal element belongs, and then the elements of the adjacent square array which are not collinear with the said principal element.

Thus in

$$\begin{array}{ccc|ccc} a_1 & a_2 & a_3 & h_1 & k_1 & l_1 \\ b_1 & c_1 & d_1 & e_1 & e_2 & e_3 \\ b_2 & c_2 & d_2 & f_1 & f_2 & f_3 \\ b_3 & c_3 & d_3 & g_1 & g_2 & g_3 \end{array}$$

the cofactor of a_2 is

$$\begin{array}{ccc} & h_1 & k_1 & l_2 \\ \hline c_1 & e_1 & e_2 & e_3 \\ c_2 & f_1 & f_2 & f_3 \\ c_3 & g_1 & g_2 & g_3 \end{array} ;$$

and the cofactor of h_1 is

$$\begin{array}{ccc|c} a_1 & a_2 & a_3 & \\ b_1 & c_1 & d_1 & e_1 \\ b_2 & c_2 & d_2 & f_1 \\ b_3 & c_3 & d_3 & g_1 \end{array} .$$

13. A bipartite of deg-order (m, n) is thus expressible as a sum of n products of two factors each, the first factors being elements taken either all from the initial line or all from the final line, and the second factors being bipartites of deg-order $(m-1, n)$.

Thus

$$\begin{array}{ccc|ccc} a_1 & a_2 & a_3 & h_1 & k_1 & l_1 \\ b_1 & c_1 & d_1 & e_1 & e_2 & e_3 \\ b_2 & c_2 & d_2 & f_1 & f_2 & f_3 \\ b_3 & c_3 & d_3 & g_1 & g_2 & g_3 \end{array}$$

$$= a_1 \cdot \begin{array}{ccc} h_1 & k_1 & l_1 \\ \hline e_1 & e_2 & e_3 \\ f_1 & f_2 & f_3 \\ g_1 & g_2 & g_3 \end{array}_{b_1 b_2 b_3} + a_2 \cdot \begin{array}{ccc} h_1 & k_1 & l_1 \\ \hline e_1 & e_2 & e_3 \\ f_1 & f_2 & f_3 \\ g_1 & g_2 & g_3 \end{array}_{c_1 c_2 c_3} + a_3 \cdot \begin{array}{ccc} h_1 & k_1 & l_1 \\ \hline e_1 & e_2 & e_3 \\ f_1 & f_2 & f_3 \\ g_1 & g_2 & g_3 \end{array}_{d_1 d_2 d_3} .$$

This recurrent law of formation of a bipartite might of course have been adopted as the definition.

14. The cofactor of any one of the secondary elements belonging to the pth array of a bipartite of deg-order (m, n) is expressible as the product of two bipartites, one of deg-order $(p-1, n)$ and the other of deg-order $(n-p, n)$, the first being got from the first $p-1$ arrays by deleting from the $(p-1)^{\text{th}}$ array all the elements not collinear with the element in question, and the second being got from the last $n-p$ arrays in the same way.

Thus in

$$\begin{array}{ccc|ccc|ccc|c} & & & h_3 & k_3 & l_3 & p_1 & p_2 & p_3 & \\ & & & h_2 & k_2 & l_2 & n_1 & n_2 & n_3 & \\ a_1 & a_2 & a_3 & h_1 & k_1 & l_1 & m_1 & m_2 & m_3 & \\ \hline b_1 & c_1 & d_1 & e_1 & e_2 & e_3 & r_1 & s_1 & u_1 & x_1 \\ b_2 & c_2 & d_2 & f_1 & f_2 & f_3 & r_2 & s_2 & u_2 & y_1 \\ b_3 & c_3 & d_3 & g_1 & g_2 & g_3 & r_3 & s_3 & u_3 & z_1 \end{array}$$

the cofactor of k_1 is

$$\begin{array}{ccc|c} a_1 & a_2 & a_3 & \\ \hline b_1 & c_1 & d_1 & e_2 \\ b_2 & c_2 & d_2 & f_2 \\ b_3 & c_3 & d_3 & g_2 \end{array} \cdot \begin{array}{ccc|c} m_1 & m_2 & m_3 & \\ \hline r_1 & s_1 & u_1 & x_1 \\ r_2 & s_2 & u_2 & y_1 \\ r_3 & s_3 & u_3 & z_1 \end{array},$$

and the cofactor of f_3 is

$$\begin{array}{ccc} & & \\ a_1 & a_2 & a_3 \\ \hline b_2 & c_2 & d_2 \end{array} \cdot \begin{array}{ccc|ccc} l_3 & p_1 & p_2 & p_3 \\ l_2 & n_1 & n_2 & n_3 \\ l_1 & m_1 & m_2 & m_3 \\ \hline & r_1 & s_1 & u_1 & x_1 \\ & r_2 & s_2 & u_2 & y_1 \\ & r_3 & s_3 & u_3 & z_1 \end{array},$$

or

$$\begin{array}{ccc} a_1 & a_2 & a_3 \\ \hline b_2 & c_2 & d_2 \end{array} \cdot \begin{array}{ccc|ccc} l_1 & l_2 & l_3 & x_1 & y_1 & z_1 \\ \hline m_1 & n_1 & p_1 & r_1 & r_2 & r_3 \\ m_2 & n_2 & p_2 & s_1 & s_2 & s_3 \\ m_3 & n_3 & p_3 & u_1 & u_2 & u_3 \end{array}.$$

15. A bipartite of deg-order (m, n) is thus expressible as a sum of n^2 products of three factors each, the first factors being elements all taken from any one of the square arrays, the pth say, the second factors being minor bipartites of deg-order $(p-1, n)$, and the third factors being minors of deg-order $(n-p, n)$.

Thus

$$\begin{array}{cc|cc|cc|cc} & & f_2 & g_2 & k_1 & k_2 & & \\ a_1 & a_2 & f_1 & g_1 & h_1 & h_2 & p_1 & q_1 \\ \hline b_1 & c_1 & d_1 & d_2 & i_1 & j_1 & m_1 & m_2 \\ b_2 & c_2 & e_1 & e_2 & i_2 & j_2 & n_1 & n_2 \end{array},$$

if we decide on taking the elements of its fourth array, is equal to

$$f_1 \cdot \begin{array}{cc|c} a_1 & a_2 & \\ \hline b_1 & c_1 & d_1 \\ b_2 & c_2 & e_1 \end{array} \cdot \begin{array}{cc|cc} h_1 & h_2 & p_1 & q_1 \\ \hline i_1 & j_2 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array} + g_1 \cdot \begin{array}{cc|c} a_1 & a_2 & \\ \hline b_1 & c_1 & d_2 \\ b_2 & c_2 & e_2 \end{array} \cdot \begin{array}{cc|cc} h_1 & h_2 & p_1 & q_1 \\ \hline i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array}$$

$$+ f_2 \cdot \begin{array}{cc|c} a_1 & a_2 & \\ \hline b_1 & c_1 & d_1 \\ b_2 & c_2 & e_1 \end{array} \cdot \begin{array}{cc|cc} k_1 & k_2 & p_1 & q_1 \\ \hline i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array} + g_2 \cdot \begin{array}{cc|c} a_1 & a_2 & \\ \hline b_1 & c_1 & d_2 \\ b_2 & c_2 & e_2 \end{array} \cdot \begin{array}{cc|cc} k_1 & k_2 & p_1 & q_1 \\ \hline i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array} \qquad (a)$$

or, if we decide on taking the elements of its 3rd array, is equal to

$$d_1 \cdot \frac{a_1}{b_1}\frac{a_2}{c_1} \cdot \begin{vmatrix} f_2 & k_1 & k_2 \\ f_1 & h_1 & h_2 \\ & i_1 & j_1 \\ & i_2 & j_2 \end{vmatrix} \begin{matrix} p_1 & q_1 \\ m_1 & m_2 \\ n_1 & n_2 \end{matrix} + e_1 \cdot \frac{a_1}{b_2}\frac{a_2}{c_2} \cdot \begin{vmatrix} f_2 & k_1 & k_2 \\ f_1 & h_1 & h_2 \\ & i_1 & j_1 \\ & i_2 & j_2 \end{vmatrix} \begin{matrix} p_1 & q_1 \\ m_1 & m_2 \\ n_1 & n_2 \end{matrix} \qquad 8$$

$$+ d_2 \cdot \frac{a_1}{b_1}\frac{a_2}{c_1} \cdot \begin{vmatrix} g_2 & k_1 & k_2 \\ g_1 & h_1 & h_2 \\ & i_1 & j_1 \\ & i_2 & j_2 \end{vmatrix} \begin{matrix} p_1 & q_1 \\ m_1 & m_2 \\ n_1 & n_2 \end{matrix} + e_2 \cdot \frac{a_1}{b_2}\frac{a_2}{c_2} \cdot \begin{vmatrix} g_2 & k_1 & k_2 \\ g_1 & h_1 & h_2 \\ & i_1 & j_1 \\ & i_2 & j_2 \end{vmatrix} \begin{matrix} p_1 & q_1 \\ m_1 & m_2 \\ n_1 & n_2 \end{matrix} .$$

16. Since a bipartite function is linear with respect to the elements of any one of its arrays, the cofactor of any of the elements (which has been shown above to be expressible as a minor bipartite or as a product of minors) is expressible also as the first differential coefficient of the function with respect to the element in question.

Hence, B denoting the bipartite whose initial line is $a_1, a_2, a_3, \ldots, a_n$, the theorem of § 13 may be alternatively stated in symbols thus—

$$\mathrm{B} = \Sigma a_r \frac{\delta \mathrm{B}}{\delta a_r} \qquad (r = 1, 2, \ldots, n)$$

and the elements of any square array of B being the elements of the determinant $|a_{1n}|$, the theorem of § 15 is

$$\mathrm{B} = \Sigma a_{rs} \frac{\delta \mathrm{B}}{\delta a_{rs}} \qquad \begin{pmatrix} r = 1, 2, \ldots, n \\ s = 1, 2, \ldots, n \end{pmatrix}$$

17. A bipartite of deg-order (m, n) is expressible as the sum of n products of two factors each, viz., a minor bipartite of any degree less than m, say of the degree p, and a minor of the degree $m-p$, the former being obtained from the first p arrays by deleting all the lines of the pth array except one, and the latter being obtained from the last $n-p$ arrays by deleting all the lines of the $(n-p)^{\text{th}}$ array except the line collinear with that formerly undeleted in the pth array from the beginning.

This theorem is deduced from the theorem of § 15 by combining those terms of the development there obtained which have a common factor. Thus, taking the first development of

$$\begin{matrix} a_1 & a_2 \\ b_1 & c_1 \\ b_2 & c_2 \end{matrix} \begin{vmatrix} f_2 & g_2 \\ f_1 & g_1 \\ d_1 & d_2 \\ e_1 & e_2 \end{vmatrix} \begin{vmatrix} k_1 & k_2 \\ h_1 & h_2 \\ i_1 & j_1 \\ i_2 & j_2 \end{vmatrix} \begin{matrix} p_1 & q_1 \\ m_1 & m_2 \\ n_1 & n_2 \end{matrix}$$

given as an example in § 15, viz.—

$$f_1 \cdot \begin{array}{cc|c} a_1 & a_2 & \\ b_1 & c_1 & d_1 \\ b_2 & c_2 & e_1 \end{array} \cdot \begin{array}{cc|cc} h_1 & h_2 & p_1 & q_1 \\ i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array} + g_1 \cdot \begin{array}{cc|c} a_1 & a_2 & \\ b_1 & c_1 & d_2 \\ b_2 & c_2 & e_2 \end{array} \cdot \begin{array}{cc|cc} h_1 & h_2 & p_1 & q_1 \\ i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array}$$

$$+ f_2 \cdot \begin{array}{cc|c} a_1 & a_2 & \\ b_1 & c_1 & d_1 \\ b_2 & c_2 & e_1 \end{array} \cdot \begin{array}{cc|cc} k_1 & k_2 & p_1 & q_1 \\ i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array} + g_2 \cdot \begin{array}{cc|c} a_1 & a_2 & \\ b_1 & c_1 & d \\ b_2 & c_2 & e_2 \end{array} \cdot \begin{array}{cc|cc} k_1 & k_2 & p_1 & q_1 \\ i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array},$$

we observe that the first two terms have the common factor

$$\begin{array}{cc|cc} h_1 & h_2 & p_1 & q_1 \\ i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array},$$

the full cofactor being

$$f_1 \cdot \begin{array}{cc|c} a_1 & a_2 & \\ b_1 & c_1 & d_1 \\ b_2 & c_2 & e_1 \end{array} + g_1 \cdot \begin{array}{cc|c} a_1 & a_2 & \\ b_1 & c_1 & d_2 \\ b_2 & c_2 & e_2 \end{array}$$

which, we know from § 13, is equal to

$$\begin{array}{cc|cc} a_1 & a_2 & f_1 & g_1 \\ b_1 & c_1 & d_1 & d_2 \\ b_2 & c_2 & e_1 & e_2 \end{array}.$$

Similarly, the cofactor of the factor common to the last two terms is seen to be

$$\begin{array}{cc|cc} a_1 & a_2 & f_2 & g_2 \\ b_1 & c_1 & d_1 & d_2 \\ b_2 & c_2 & e_1 & e_2 \end{array}.$$

Hence we have as an example of the present theorem—

$$\begin{array}{cc|cc|cc|cc} a_1 & a_2 & f_2 & g_2 & k_1 & k_2 & & \\ & & f_1 & g_1 & h_1 & h_2 & p_1 & q_1 \\ b_1 & c_1 & d_1 & d_2 & i_1 & j_1 & m_1 & m_2 \\ b_2 & c_2 & e_1 & e_2 & i_2 & j_2 & n_1 & n_2 \end{array} = \begin{array}{cc|cc} a_1 & a_2 & f_1 & g_1 \\ b_1 & c_1 & d_1 & d_2 \\ b_2 & c_2 & e_1 & e_2 \end{array} \cdot \begin{array}{cc|cc} h_1 & h_2 & p_1 & q_1 \\ i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array} + \begin{array}{cc|cc} a_1 & a_2 & f_2 & g_2 \\ b_1 & c_1 & d_1 & d_2 \\ b_2 & c_2 & e_1 & e_2 \end{array} \cdot \begin{array}{cc|cc} k_1 & k_2 & p_1 & q_1 \\ i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array}. \qquad (a)$$

Had we combined the first and third terms of the same development, and then the second and fourth, we should have obtained the example—

$$\begin{array}{cc|cc|cc|cc} a_1 & a_2 & f_2 & g_2 & k_1 & k_2 & & \\ & & f_1 & g_1 & h_1 & h_2 & p_1 & q_1 \\ b_1 & c_1 & d_1 & d_2 & i_1 & j_1 & m_1 & m_2 \\ b_2 & c_2 & e_1 & e_2 & i_2 & j_2 & n_1 & n_2 \end{array} = \begin{array}{cc|c} a_1 & a_2 & \\ b_1 & c_1 & d_1 \\ b_2 & c_2 & e_1 \end{array} \cdot \begin{array}{cc|cc|cc} f_2 & k_1 & k_2 & & & \\ f_1 & h_1 & h_2 & p_1 & q_1 & \\ & i_1 & j_1 & m_1 & m_2 & \\ & i_2 & j_1 & n_1 & n_2 & \end{array} + \begin{array}{cc|c} a_1 & a_2 & \\ b_1 & c_1 & d_2 \\ b_2 & c_2 & e_2 \end{array} \cdot \begin{array}{cc|cc|cc} g_2 & k_1 & k_2 & & & \\ g_1 & h_1 & h_2 & p_1 & q_1 & \\ & i_1 & j_1 & m_1 & m_2 & \\ & i_2 & j_2 & n_1 & n_2 & \end{array}.$$

Again, by combining the first and third terms of the *second* development in § 15, we should have the case where the one factor is of the second degree, and the other of the sixth, viz.—

$$\begin{array}{ccc|cc|cc|cc} & & f_2 & g_2 & k_1 & k_2 & & & & \\ a_1 & a_2 & f_1 & g_1 & h_1 & h_2 & p_1 & q_1 & = \dfrac{a_1}{b_1}\dfrac{a_2}{c_1} \cdot \dfrac{f_2}{f_1}\dfrac{g_2}{g_1} & \dfrac{k_1}{h_1}\dfrac{k_2}{h_2} & \dfrac{p_1}{m_1}\dfrac{q_1}{m_2} + \dfrac{a_1}{b_2}\dfrac{a_2}{c_2} \cdot \dfrac{f_2}{e_1}\dfrac{g_2}{e_2} & \dfrac{k_1}{h_1}\dfrac{k_2}{h_2} & \dfrac{p_1}{m_1}\dfrac{q_1}{m_2} \\ b_1 & c_1 & d_1 & d_2 & i_1 & j_1 & m_1 & m_2 & & \dfrac{k_1}{i_1}\dfrac{k_2}{j_1} & \dfrac{p_1}{m_1}\dfrac{q_1}{m_2} & & \dfrac{k_1}{i_1}\dfrac{k_2}{j_1} & \dfrac{p_1}{m_1}\dfrac{q_1}{m_2} \\ b_2 & c_2 & e_1 & e_2 & i_2 & j_2 & n_1 & n_2 & & \dfrac{k_1}{i_2}\dfrac{k_2}{j_2} & \dfrac{p_1}{n_1}\dfrac{q_1}{n_2} & & \dfrac{k_1}{i_2}\dfrac{k_2}{j_2} & \dfrac{p_1}{n_1}\dfrac{q_1}{n_2} \end{array}.$$

The case where the one factor is of the 1st degree and the other of the 7th falls under the theorem of § 13, which may thus be looked on as a particular case of the present theorem.

18. Two minors such as those of each term of the development in the preceding paragraph—that is to say, minors which, when multiplied, give terms that are all terms of the parent bipartite—may be called *complementary minors*.

19. A bipartite of deg-order (m, n) is expressible as a sum of n^2 products of three factors each, the first being an element of the initial line, the second an element of the final line, and the third the minor bipartite of deg-order $(m-2, n)$, which is obtained from the original by deleting the initial and final lines, and those lines of the first and last square arrays which are not collinear with one of the said pair of elements.

Thus

$$\begin{array}{ccc|cc} a_1 & a_2 & f_1 & g_1 \\ b_1 & c_1 & d_1 & d_2 \\ b_2 & c_2 & e_1 & e_2 \end{array} = a_1 f_1 \cdot \frac{b_1}{d_1}\frac{b_2}{e_1} + a_1 g_1 \frac{b_1}{d_2}\frac{b_2}{e_2} + a_2 f_1 \cdot \frac{c_1}{d_1}\frac{c_2}{e_1} + a_2 g_1 \cdot \frac{c_1}{d_2}\frac{c_2}{e_2}.$$

This of course is but the result of a double application of the theorem of § 13.

20. A bipartite function may be expressed as a bipartite of lower degree, in which elements occur that are themselves bipartites, and to which, on that account, the name *compound bipartite* may be given.

21. The theorem of § 17 is the case of this where the compound bipartite is of the *second* degree. Thus the identity (α) there given may be written also in the form

$$\begin{array}{ccc|ccc|cc} & & & f_2 & g_2 & k_1 & k_2 & & \\ a_1 & a_2 & & f_1 & g_1 & h_1 & h_2 & p_1 & q_1 \\ b_1 & c_1 & & d_1 & d_2 & i_1 & j_1 & m_1 & m_2 \\ b_2 & c_2 & & e_1 & e_2 & i_2 & j_2 & n_1 & n_2 \end{array} = \frac{\begin{array}{cc|cc} a_1 & a_2 & f_1 & g_1 \\ b_1 & c_1 & d_1 & d_2 \\ b_2 & c_2 & e_1 & e_2 \end{array} \cdot \begin{array}{cc|cc} h_1 & h_2 & p_1 & q_1 \\ i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array}}{\begin{array}{cc|cc} a_1 & a_2 & f_2 & g_2 \\ b_1 & c_1 & d_1 & d_2 \\ b_2 & c_2 & e_1 & e_2 \end{array} \cdot \begin{array}{cc|cc} k_1 & k_2 & p_1 & q_1 \\ i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array}};$$

and so of the others.

22. The theorem of § 15 is the case where the compound bipartite is of the third degree, and its square array is a square array of the original bipartite. Thus the identity (α) there given may be written also in the form

$$\begin{array}{cc|cc|cc|cc} & & f_2 & g_2 & k_1 & k_2 & & \\ a_1 & a_2 & f_1 & g_1 & h_1 & h_2 & p_1 & q_1 \\ \hline b_1 & c_1 & d_1 & d_2 & i_1 & j_1 & m_1 & m_2 \\ b_2 & c_2 & e_1 & e_2 & i_2 & j_2 & n_1 & n_2 \end{array} = \begin{array}{cc|c} \mathrm{P}_3 & \mathrm{Q}_3 & \\ \hline f_2 & g_2 & \mathrm{R}_4 \\ f_1 & g_1 & \mathrm{S}_4 \end{array}$$

where

$$\mathrm{P}_3 = \begin{array}{cc|c} a_1 & a_2 & \\ \hline b_1 & c_1 & d_1 \\ b_2 & c_2 & e_1 \end{array}, \quad \mathrm{Q}_3 = \begin{array}{cc|c} a_1 & a_2 & \\ \hline b_1 & c_1 & d_2 \\ b_2 & c_2 & e_2 \end{array},$$

$$\mathrm{R}_4 = \begin{array}{cc|cc} k_1 & k_2 & p_1 & q_1 \\ \hline i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array}, \quad \mathrm{S}_4 = \begin{array}{cc|cc} h_1 & h_2 & p_1 & q_1 \\ \hline i_1 & j_1 & m_1 & m_2 \\ i_2 & j_2 & n_1 & n_2 \end{array}.$$

23. The theorem of § 19 is the rather important case where the compound bipartite is again of the third degree, but having for its initial and final lines the initial and final lines of the original bipartite.

Thus

$$\begin{array}{cc|cc|cc|cc} & & f_2 & g_2 & k_1 & k_2 & & \\ a_1 & a_2 & f_1 & g_1 & h_1 & h_2 & p_1 & q_1 \\ \hline b_1 & c_1 & d_1 & d_2 & i_1 & j_1 & m_1 & m_2 \\ b_2 & c_2 & e_1 & e_2 & i_2 & j_2 & n_1 & n_2 \end{array} = \begin{array}{cc|c} a_1 & a_2 & \\ \hline \mathrm{U}_6 & \mathrm{X}_6 & p_1 \\ \mathrm{V}_6 & \mathrm{Y}_6 & q_1 \end{array}$$

where

$$\mathrm{U}_6 = \begin{array}{cc|cc|c} f_2 & g_2 & k_1 & k_2 & \\ \hline f_1 & g_1 & h_1 & h_2 & \\ \hline b_1 & d_1 & d_2 & i_1 & j_1 & m_1 \\ b_2 & e_1 & e_2 & i_2 & j_2 & n_1 \end{array}, \quad \mathrm{X}_6 = \begin{array}{cc|cc|c} f_2 & g_2 & k_1 & k_2 & \\ \hline f_1 & g_1 & h_1 & h_2 & \\ \hline c_1 & d_1 & d_2 & i_1 & j_1 & m_1 \\ c_2 & e_1 & e_2 & i_2 & j_2 & n_1 \end{array},$$

$$\mathrm{V}_6 = \begin{array}{cc|cc|c} f_2 & g_2 & k_1 & k_2 & \\ \hline f_1 & g_1 & h_1 & h_2 & \\ \hline b_1 & d_1 & d_2 & i_1 & j_1 & m_2 \\ b_2 & e_1 & e_2 & i_2 & j_2 & n_2 \end{array}, \quad \mathrm{Y}_6 = \begin{array}{cc|cc|c} f_2 & g_2 & k_1 & k_2 & \\ \hline f_1 & g_1 & h_1 & h_2 & \\ \hline c_1 & d_1 & d_2 & i_1 & j_1 & m_2 \\ c_2 & e_1 & e_2 & i_2 & j_2 & n_2 \end{array}.$$

24. There are, however, other modes of expressing a bipartite of a degree higher than the third as a compound bipartite of the third degree. These we obtain by making use of both § 15 and § 17.

For example, by § 17 (or § 13) we have

$$\begin{array}{cc|cc|cc|cc} & & f_2 & g_2 & k_1 & k_2 & & \\ a_1 & a_2 & f_1 & g_1 & h_1 & h_2 & p_1 & q_1 \\ \hline b_1 & c_1 & d_1 & d_2 & i_1 & j_1 & m_1 & m_2 \\ b_2 & c_2 & e_1 & e_2 & i_2 & j_2 & n_1 & n_2 \end{array} = a_1 \cdot \begin{array}{cc|cc|c} f_2 & g_2 & k_1 & k_2 & \\ \hline f_1 & g_1 & h_1 & h_2 & \\ \hline b_1 & d_1 & d_2 & i_1 & j_1 & m_1 \\ b_2 & e_1 & e_2 & i_2 & j_2 & n_1 \end{array} + a_2 \cdot \begin{array}{cc|cc|c} f_2 & g_2 & k_1 & k_2 & \\ \hline f_1 & g_1 & h_1 & h_2 & \\ \hline c_1 & d_1 & d_2 & i_1 & j_1 & m_1 \\ c_2 & e_1 & e_2 & i_2 & j_2 & n_1 \end{array} \begin{array}{cc|cc|c} & & & & \\ \hline & & & & \\ \hline p_1 & q_1 & & & \\ m_1 & m_2 & & & \\ n_1 & n_2 & & & \end{array} \quad (\alpha)$$

and by § 15 the cofactor of a_1 is equal to

$$\begin{array}{c|cc|c} & f_2 & g_2 & k_1 \\ & f_1 & g_1 & h_1 \\ \hline b_1 & d_1 & d_2 & \\ b_2 & e_1 & e_2 & \end{array} \cdot \begin{array}{c|cc} & p_1 & q_1 \\ \hline i_1 & m_1 & m_2 \\ i_2 & n_1 & n_2 \end{array} + \begin{array}{c|cc|c} & f_2 & g_2 & k_2 \\ & f_1 & g_1 & h_2 \\ \hline b_1 & d_1 & d_2 & \\ b_2 & e_1 & e_2 & \end{array} \cdot \begin{array}{c|cc} & p_1 & q_1 \\ \hline j_1 & m_1 & m_2 \\ j_2 & n_1 & n_2 \end{array} \qquad (\beta_1)$$

and the cofactor of a_2 is equal to

$$\begin{array}{c|cc|c} & f_2 & g_2 & k_1 \\ & f_1 & g_1 & h_1 \\ \hline c_1 & d_1 & d_2 & \\ c_2 & e_1 & e_2 & \end{array} \cdot \begin{array}{c|cc} & p_1 & q_2 \\ \hline i_1 & m_1 & m_2 \\ i_2 & n_1 & n_2 \end{array} + \begin{array}{c|cc|c} & f_2 & g_2 & k_2 \\ & f_1 & g_1 & h_2 \\ \hline c_1 & d_1 & d_2 & \\ c_2 & e_1 & e_2 & \end{array} \cdot \begin{array}{c|cc} & p_1 & q_1 \\ \hline j_1 & m_1 & m_2 \\ j_2 & n_1 & n_2 \end{array} \qquad (\beta_2)$$

Hence

$$\begin{array}{cc|cc|cc|cc} & & f_2 & g_2 & k_1 & k_2 & & \\ a_1 & a_2 & f_1 & g_1 & h_1 & h_2 & p_1 & q_1 \\ \hline b_1 & c_1 & d_1 & d_2 & i_1 & j_1 & m_1 & m_2 \\ b_2 & c_2 & e_1 & e_2 & i_2 & j_2 & n_1 & n_2 \end{array} = \begin{array}{cc|c} a_1 & a_2 & \\ \hline \mathrm{P}_4 & \mathrm{M}_4 & \mathrm{R}_3 \\ \mathrm{Q}_4 & \mathrm{N}_4 & \mathrm{S}_3 \end{array}$$

where

$$\mathrm{P}_4 = \begin{array}{c|cc|c} & f_2 & g_2 & k_1 \\ & f_1 & g_1 & h_1 \\ \hline b_1 & d_1 & d_2 & \\ b_2 & e_1 & e_2 & \end{array}, \quad \mathrm{M}_4 = \begin{array}{c|cc|c} & f_2 & g_2 & k_1 \\ & f_1 & g_1 & h_1 \\ \hline c_1 & d_1 & d_2 & \\ c_2 & e_1 & e_2 & \end{array}, \quad \mathrm{R}_3 = \begin{array}{c|cc} & p_1 & q_1 \\ \hline i_1 & m_1 & m_2 \\ i_2 & n_1 & n_2 \end{array}$$

$$\mathrm{Q}_4 = \begin{array}{c|cc|c} & f_2 & g_2 & k_2 \\ & f_1 & g_1 & h_2 \\ \hline b_1 & d_1 & d_2 & \\ b_2 & e_1 & e_2 & \end{array}, \quad \mathrm{N}_4 = \begin{array}{c|cc|c} & f_2 & g_2 & k_2 \\ & f_1 & g_1 & h_2 \\ \hline c_1 & d_1 & d_2 & \\ c_2 & e_1 & e_2 & \end{array}, \quad \mathrm{S}_3 = \begin{array}{c|cc} & p_1 & q_1 \\ \hline j_1 & m_1 & m_2 \\ j_2 & n_1 & n_2 \end{array}$$

It will be observed that, in using § 15 the second time here, it is necessary to do so in such a way that each term of (β_2) shall have a factor common to the corresponding term of (β_1).

25. When we note that in using the theorem of § 17 in the preceding paragraph, several other identities might have been got in place of (α), and that in using the theorem of § 15 we might have chosen several other pairs of identities in place of $(\beta_1)(\beta_2)$, it is clear that we have not by any means exhausted the possible ways of expressing the given bipartite as a compound bipartite of the 3rd degree.

There is little difficulty in seeing what the theorem is which includes these different forms in the same way as theorems of § 17 and § 15 include all the forms of §§ 21, 22; but the formulating of it would at the present stage be troublesome [*see* § 42].

26. The expression of a bipartite of a degree higher than the 4th as a compound bipartite of the 4th degree, and generally the expression of a bipar-

tite of a degree higher than the mth as a compound bipartite of the mth degree, can be obtained in a manner similar to that of § 24 by repeated use of the theorems of §§ 15, 17.

27. A more expeditious and more instructive method, however, is to make use of the already obtained transformations into compound bipartites of the 2nd and 3rd degrees.

Suppose, for example, that it is required to express the bipartite of the 6th degree—

$$\begin{array}{ccc|ccc|ccc} & & & h_3 & k_3 & l_3 & r_1 & r_2 & r_3 \\ & & & h_2 & k_2 & l_2 & n_1 & n_2 & n_3 \\ a_1 & a_2 & a_3 & h_1 & k_1 & l_1 & m_1 & m_2 & m_3 \\ \hline b_1 & c_1 & d_1 & e_1 & e_2 & e_3 & x_1 & y_1 & z_1 \\ b_2 & c_2 & d_2 & f_1 & f_2 & f_3 & & & \\ b_3 & c_3 & d_3 & g_1 & g_2 & g_3 & & & \end{array}, \quad \text{or} \quad \beta_6 \quad \text{say,}$$

as a compound bipartite of the 4th degree. A probable form for the latter would be that in which the initial and final lines were the same as those of the original, and the elements of both its square arrays bipartites of the 2nd degree. Let us denote this form by

$$\begin{array}{ccc|ccc} a_1 & a_2 & a_3 & x_1 & y_1 & z_1 \\ \hline \mathrm{P}_1 & \mathrm{Q}_1 & \mathrm{R} & \mathrm{S}_1 & \mathrm{S}_2 & \mathrm{S}_3 \\ \mathrm{P}_2 & \mathrm{Q}_2 & \mathrm{R}_2 & \mathrm{T}_1 & \mathrm{T}_2 & \mathrm{T}_3 \\ \mathrm{P}_3 & \mathrm{Q}_3 & \mathrm{R}_3 & \mathrm{U}_1 & \mathrm{U}_2 & \mathrm{U}_3 \end{array}, \quad \text{or} \quad \mathrm{B}_4 .$$

Then, changing both β_6 and B_4 into bipartites of the 3rd degree by means of the theorem of § 23, we obtain on comparison of the two results—

$$\frac{\mathrm{P}_1\ \mathrm{P}_2\ \mathrm{P}_3}{\mathrm{S}_1\ \mathrm{T}_1\ \mathrm{U}_1} = \begin{array}{ccc|ccc} b_1 & b_2 & b_3 & m_1 & n_1 & r_1 \\ e_1 & f_1 & g_1 & h_1 & h_2 & h_3 \\ e_2 & f_2 & g_2 & k_1 & k_2 & k_3 \\ e_3 & f_3 & g_3 & l_1 & l_2 & l_3 \end{array} = \frac{b_1\ b_2\ b_3}{\Delta_2} \left| \frac{m_1\ n_1\ r_1}{\Delta_3} \right., \text{ say.}$$

$$\frac{\mathrm{P}_1\ \mathrm{P}_2\ \mathrm{P}_3}{\mathrm{S}_2\ \mathrm{T}_2\ \mathrm{U}_2} = \frac{b_1\ b_2\ b_3}{\Delta_2} \left| \frac{m_2\ n_2\ r_2}{\Delta_3} \right.,$$

and seven other similar equations. But by the theorem of § 21 these may be transformed into

$$\frac{\mathrm{P}_1,\ \mathrm{P}_2,\ \mathrm{P}_3,}{\mathrm{S}_1,\ \mathrm{T}_1,\ \mathrm{U}_1} = \frac{\dfrac{b_1\ b_2\ b_3}{e_1\ f_1\ g_1},\ \dfrac{b_1\ b_2\ b_3}{e_2\ f_2\ g_2},\ \dfrac{b_1\ b_2\ b_3}{e_3\ f_3\ g_3}}{\dfrac{m_1\ n_1\ r_1}{h_1\ h_2\ h_3},\ \dfrac{m_1\ n_1\ r_1}{k_1\ k_2\ k_3},\ \dfrac{m_1\ n_1\ r_1}{l_1\ l_2\ l_3}},$$

$$\frac{\mathrm{P}_1,\ \mathrm{P}_2,\ \mathrm{P}_3}{\mathrm{S}_2,\ \mathrm{T}_2,\ \mathrm{U}_2} = \frac{\dfrac{b_1\ b_2\ b_3}{e_1\ f_1\ g_1},\ \dfrac{b_1\ b_2\ b_3}{e_2\ f_2\ g_2},\ \dfrac{b_1\ b_2\ b_3}{e_3\ f_3\ g_3}}{\dfrac{m_2\ n_2\ r_2}{h_1\ h_2\ h_3},\ \dfrac{m_2\ n_2\ r_2}{k_1\ k_2\ k_3},\ \dfrac{m_2\ n_2\ r_2}{l_1\ l_2\ l_3}},$$

. . . . . .

which are evidently all satisfied by

$$P_1=\frac{b_1\ b_2\ b_3}{e_1\ f_1\ g_1},\quad P_2=\frac{b_1\ b_2\ b_3}{e_2\ f_2\ g_2},\quad P_3=\frac{b_1\ b_2\ b_3}{e_3\ f_3\ g_3},$$

$$Q_1=\frac{c_1\ c_2\ c_3}{e_1\ f_1\ g_1},\quad \&c.$$

The problem is thus solved.

28. Of compound bipartites, some interest attaches to that special form, each of whose elements is the cofactor of the corresponding element in another bipartite, and which, in reference to an analogue in the theory of determinants, we may term the bipartite *adjugate* to the parent bipartite.

29. The bipartite adjugate to a bipartite of the mth degree is equal to the $(m-1)^{\text{th}}$ power of the latter. The bipartite adjugate to

$$\frac{a_1\ a_2\ a_3}{b_1\ c_1\ d_1},\quad \text{or}\quad \beta_2,$$

is

$$\frac{b_1\ c_1\ d_1}{a_1\ a_2\ a_3},\quad \text{or}\quad B_2:$$

hence evidently

$$B_2=\beta_2.$$

The bipartite adjugate to

$$\begin{array}{ccc|c} a_1 & a_2 & a_3 & \\ \hline b_1 & c_1 & d_1 & e_1 \\ b_2 & c_2 & d_2 & f_1 \\ b_3 & c_3 & d_3 & g_1, \end{array}\quad \text{or}\quad \beta_3,$$

is

$$\begin{array}{ccc|c} A_1 & A_2 & A_3 & \\ \hline a_1e_1 & a_2e_1 & a_3e_1 & E_1 \\ a_1f_1 & a_2f_1 & a_3f_1 & F_1 \\ a_1g_1 & a_2g_1 & a_3g_1 & G_1, \end{array}\quad \text{or}\quad B_3,$$

if the capital letters be used to denote the cofactors of the corresponding small letters in β_3. Now (§ 13)

$$\beta_3=a_1A_1+a_2A_2+a_3A_3,$$

and

$$\beta_3=e_1E_1+f_1F_1+g_1G_1;$$

and multiplying together the two dexter members we obtain nine terms, which are exactly the nine terms of B_3. Hence

$$B_3=\beta_3^2.$$

Thirdly, denoting the bipartite adjugate to

$$\begin{array}{ccc|ccc} a_1 & a_2 & a_3 & h_1 & k_1 & l_1 \\ b_1 & c_1 & d_1 & e_1 & e_2 & e_3 \\ b_2 & c_2 & d_2 & f_1 & f_2 & f_3 \\ b_3 & c_3 & d_3 & g_1 & g_2 & g_3 \end{array}, \quad \text{or} \quad \beta_4,$$

by

$$\begin{array}{ccc|ccc} \mathrm{A}_1 & \mathrm{A}_2 & \mathrm{A}_3 & \mathrm{H}_1 & \mathrm{K}_1 & \mathrm{L}_1 \\ \mathrm{B}_1 & \mathrm{C}_1 & \mathrm{D}_1 & \mathrm{E}_1 & \mathrm{E}_2 & \mathrm{E}_3 \\ \mathrm{B}_2 & \mathrm{C}_2 & \mathrm{D}_2 & \mathrm{F}_1 & \mathrm{F}_2 & \mathrm{F}_3 \\ \mathrm{B}_3 & \mathrm{C}_3 & \mathrm{D}_3 & \mathrm{G}_1 & \mathrm{G}_2 & \mathrm{G}_3 \end{array}, \quad \text{or} \quad \mathrm{B}_4$$

and, proceeding on the same lines as in the foregoing case, we have

(§ 13) $\qquad \beta_4 = a_1\mathrm{A}_1 + a_2\mathrm{A}_2 + a_3\mathrm{A}_3 ,$

(§ 13) $\qquad \beta_4 = h_1\mathrm{H}_1 + k_1\mathrm{K}_1 + l_1\mathrm{L}_1 .$

Also, by an extension of the same theorem (§ 17),

$$\beta_4 = \begin{array}{ccc} a_1 & a_2 & a_3 \\ b_1 & c_1 & d_1 \end{array} \begin{array}{ccc} h_1 & k_1 & l_1 \\ e_1 & e_2 & e_3 \end{array} + \begin{array}{ccc} a_1 & a_2 & a_3 \\ b_2 & c_2 & d_2 \end{array} \cdot \begin{array}{ccc} h_1 & k_1 & l_1 \\ f_1 & f_2 & f_3 \end{array} + \begin{array}{ccc} a_1 & a_2 & a_3 \\ b_3 & c_3 & d_3 \end{array} \cdot \begin{array}{ccc} h_1 & k_1 & l_1 \\ g_1 & g_2 & g_3 \end{array} .$$

Multiplying together the three dexter members of these equations we obtain an expression of twenty-seven terms which are exactly the twenty-seven terms of B_4. Hence

$$\mathrm{B}_4 = \beta_4^3 .$$

The same mode of demonstration is evidently applicable when the bipartites are of any higher degree.

30. If the bipartite adjugate to a given bipartite be formed, any minor of it of the rth degree is equal to the product obtained by multiplying the cofactor of the corresponding minor in the original bipartite by the $(r-1)^{\text{th}}$ power of the latter.

For example, in the third case of the preceding paragraph, the minor

$$\begin{array}{ccc} \mathrm{D}_1 & \mathrm{D}_2 & \mathrm{D}_3 \\ \mathrm{E}_1 & \mathrm{F}_1 & \mathrm{G}_1 \end{array} = \frac{a_3 \begin{array}{ccc} h_1 & k_1 & l_1 \\ e_1 & e_2 & e_3 \end{array} , \; a_3 \begin{array}{ccc} h_1 & k_1 & l_1 \\ f_1 & f_2 & f_3 \end{array} , \; a_3 \begin{array}{ccc} h_1 & k_1 & l_1 \\ g_1 & g_2 & g_3 \end{array}}{h_1 \begin{array}{ccc} a_1 & a_2 & a_3 \\ b_1 & c_1 & d_1 \end{array} , \; h_1 \begin{array}{ccc} a_1 & a_2 & a_3 \\ b_2 & c_2 & d_2 \end{array} , \; h_1 \begin{array}{ccc} a_1 & a_2 & a_3 \\ b_3 & c_3 & d_3 \end{array}}$$

$$= a_3h_1 \cdot \begin{array}{ccc|ccc} a_1 & a_2 & a_3 & h_1 & k_1 & l_1 \\ b_1 & c_1 & d_1 & e_1 & e_2 & e_3 \\ b_2 & c_2 & d_2 & f_1 & f_2 & f_3 \\ b_3 & c_3 & d_3 & g_1 & g_2 & g_3 \end{array} ,$$

$$= a_3h_1 \cdot (\beta)^1 ;$$

and a_3h_1 is the cofactor of that minor of β_4 which corresponds with the minor $\begin{array}{ccc} \mathrm{D}_1 & \mathrm{D}_2 & \mathrm{D}_3 \\ \mathrm{E}_1 & \mathrm{F}_1 & \mathrm{G}_1 \end{array}$ of B_4.

31. To every general theorem which takes the form of an identical relation between a number of the minors of a bipartite or between the bipartite itself and a number of its minors, there corresponds another theorem derivable from the former by merely substituting for every minor its cofactor in the bipartite, and then multiplying any term by such a power of the bipartite as will make all the terms of the same degree.

This is the important Law of Complementaries already known to hold good in regard to Determinants and Pfaffians. Any class, indeed, of algebraical combinatory functions, concerning which we can assert the truth of two theorems like those of §§ 29, 30, is ruled by the Law of Complementaries. The mode of establishing the law is literally the same for all. (See my *Theory of Determinants*, pp. 141, 142.)

32. If all the rows or all the columns of any square array of a bipartite be identical the bipartite is resolvable into two factors.

For by the theorem of § 17 the bipartite is expressible as a sum of products of pairs of factors, and all these products by the datum have one factor in common. Thus

$$\begin{array}{ccc|c} a_1 & a_2 & a \\ b_1 & c_1 & d_1 & e_1 & e_2 & e_3 \\ b_2 & c_2 & d_2 & e_1 & e_2 & e_3 \\ b_3 & c_3 & d_3 & e_1 & e_2 & e_3 \\ \hline & & & f_1 & g_1 & h_1 & k_1 \\ & & & f_2 & g_2 & h_2 & l_1 \\ & & & f_3 & g_3 & h_3 & m_1 \end{array} = \left\{ \begin{array}{ccc} a_1 & a_2 & a_3 \\ b_1 & c_1 & d_1 \end{array} + \begin{array}{ccc} a_1 & a_2 & a_3 \\ b_2 & c_2 & d_2 \end{array} + \begin{array}{ccc} a_1 & a_2 & a_3 \\ b_3 & c_3 & d_3 \end{array} \right\} \times \begin{array}{ccc|c} e_1 & e_2 & e_3 \\ f_1 & g_1 & h_1 & k_1 \\ f_2 & g_2 & h_2 & l_1 \\ f_3 & g_3 & h_3 & m_1 \end{array}.$$

33. Any power of a bipartite of the second degree may be expressed as a bipartite.

For example—

$$\begin{array}{ccc|c} a & b & c \\ ax & ay & az & x \\ bx & by & bz & y \\ cx & cy & cz & z \end{array} = \begin{array}{ccc|c} a & b & c \\ x & y & z & ax \\ x & y & z & by \\ x & y & z & cz \end{array} = \left(\begin{array}{ccc} a & b & c \\ x & y & z \end{array} \right)^2;$$

and

$$\begin{array}{ccc|ccc} a & b & c & x & y & z \\ ax & ay & az & ax & bx & cx \\ bx & by & bz & ay & by & cy \\ cx & cy & cz & az & bz & cz \end{array} = \begin{array}{ccc|ccc} a & b & c & x & y & z \\ x & y & z & a^2x & abx & acx \\ x & y & z & aby & b^2y & bcy \\ x & y & z & acz & bcz & c^2z \end{array},$$

$$= \begin{array}{ccc|ccc} a & b & c & ax & by & cz \\ x & y & z & ax & ax & ax \\ x & y & z & by & by & by \\ x & y & z & cz & cz & cz \end{array},$$

$$= \left(\begin{array}{ccc} a & b & c \\ x & y & z \end{array} \right)^3 \text{ by § 32.}$$

34. The product of two bipartites of the third degree may be expressed as a bipartite of the third degree.

For example—

$$\begin{array}{|ccc|}\hline a_1 & a_2 & a_3 \\ b_1 & c_1 & d_1 \\ b_2 & c_2 & d_2 \\ b_3 & c_3 & d_3 \\ \hline\end{array}\begin{matrix} e_1 \\ f_1 \\ g_1 \end{matrix} \times \begin{array}{|ccc|}\hline a_1 & a_2 & a_3 \\ \beta_1 & \gamma_1 & \delta_1 \\ \beta_2 & \gamma_2 & \delta_2 \\ \beta_3 & \gamma_3 & \delta_3 \\ \hline\end{array}\begin{matrix} \epsilon_1 \\ \phi_1 \\ \chi_1 \end{matrix} = \begin{array}{|ccc|}\hline \frac{b_1\ b_2\ b_3}{e_1\ f_1\ g_1}, & \frac{c_1\ c_2\ c_3}{e_1\ f_1\ g_1}, & \frac{d_1\ d_2\ d_3}{e_1\ f_1\ g_1} \\ a_1\epsilon_1 & a_2\epsilon_1 & a_3\epsilon_1 \\ a_1\phi_1 & a_2\phi_1 & a_3\phi_1 \\ a_1\chi_1 & a_2\chi_1 & a_3\chi_1 \\ \hline\end{array}\begin{matrix} \frac{a_1\ a_2\ a_3}{\beta_1\ \gamma_1\ \delta_1} \\ \frac{a_1\ a_2\ a_3}{\beta_2\ \gamma_2\ \delta_2} \\ \frac{a_1\ a_2\ a_3}{\beta_3\ \gamma_3\ \delta_3} \end{matrix}$$

The law of formation of the product is the same for all orders.

35. The product of a bipartite of deg-order $(3, n)$ by the $(n-2)^{\text{th}}$ power of the determinant of its square array is expressible as a determinant of the $(n+1)^{\text{th}}$ order.

Thus denoting the determinant $|b_1\ c_2\ d_3\ e_4|$ by Δ, and its adjugate by $|B_1\ C_2\ D_3\ E_4|$, we have

$$b_1\ c_2\ d_3\ e_4| \times \begin{array}{c|cccc} & a_1 & a_2 & a_3 & a_4 \\ f_1 & b_1 & c_1 & d_1 & e_1 \\ g_1 & b_2 & c_2 & d_2 & e_2 \\ h_1 & b_3 & c_3 & d_3 & e_3 \\ k_1 & b_4 & c_4 & d_4 & e_4 \end{array} = \begin{array}{c|cccc} & a_1 & a_2 & a_3 & a_4 \\ f_1 & b_1\Delta & c_1\Delta & d_1\Delta & e_1\Delta \\ g_1 & b_2\Delta & c_2\Delta & d_2\Delta & e_2\Delta \\ h_1 & b_3\Delta & c_3\Delta & d_3\Delta & e_3\Delta \\ k_1 & b_4\Delta & c_4\Delta & d_4\Delta & e_4\Delta \end{array}$$

$$= \begin{array}{c|cccc} & a_1 & a_2 & a_3 & a_4 \\ f_1 & |C_2D_3E_4| & -|B_2D_3E_4| & |B_2C_3E_4| & -|B_2C_3D_4| \\ g_1 & -|C_1D_3E_4| & |B_1D_3E_4| & -|B_1C_3E_4| & |B_1C_3D_4| \\ h_1 & |C_1D_2E_4| & -|B_1D_2E_4 & |B_1C_2E_4| & -|B_1C_2D_4 \\ k & -|C_1D_2E_3| & |B_1D_2E_3| & -|B_1C_2E_3| & |B_1C_2D_3 \end{array}$$

$$= -\begin{vmatrix} 0 & a_1 & a_2 & a_3 & a_4 \\ f_1 & B_1 & C_1 & D_1 & E_1 \\ g_1 & B_2 & C_2 & D_2 & E_2 \\ h_1 & B_3 & C_3 & D_3 & E_3 \\ k_1 & B_4 & C_4 & D_4 & E_4 \end{vmatrix}.$$

36. § 22 makes it evident that the foregoing theorem is quite generally true —that is to say, is true when the bipartite is of deg-order (m, n) (m being of course greater than 3), and when the determinant taken is the determinant of *any one* of the square arrays of the bipartite.

37. A very much wider definition of a bipartite may be given than that with which we started. The arrays lying between the initial and final lines,

instead of being squares, may be merely rectangles, the length of the first rectangle being the same as that of the initial line, the length of the second the same as the breadth of the first, the length of the third the same as the breadth of the second, and so on. Thus, starting with a line of m elements, we draw the separating bar and write n rows of m elements each, then r columns of n elements each, then s rows of r elements each, and end with a line of s elements. The case of this where $m=2$, $n=3$, $r=4$, $s=1$ is represented by

$$\begin{array}{cc|cccc} a_1 & a_2 & & & & \\ \hline b_1 & c_1 & d_1 & d_2 & d_3 & d_4 \\ b_2 & c_2 & e_1 & e_2 & e_3 & e_4 \\ b_3 & c_3 & f_1 & f_2 & f_3 & f_4 \\ \hline & & g_1 & h_1 & k_1 & l_1 \end{array} \quad m_1$$

38. A little consideration serves to show that almost every theorem we have given can be extended so as to hold true of bipartites with rectangular arrays whose length and breadth are different. Indeed, this extended definition was not adopted from the first, only because it was seen that by doing so the difficulties of exposition would have been considerably increased.

39. Of course any bipartite with arrays that are merely rectangular may be expressed as a bipartite with square arrays by the introduction of a sufficient number of zero elements; and in this way what we have called the more general form of bipartite may also be looked upon as a degeneration of the particular form. Thus the square-arrayed bipartite

$$\begin{array}{cccc|cccc} a_1 & a_2 & 0 & 0 & & & & \\ \hline b_1 & c_1 & 0 & 0 & d_1 & d_2 & d_3 & d_4 \\ b_2 & c_2 & 0 & 0 & e_1 & e_2 & e_3 & e_4 \\ b_3 & c_3 & 0 & 0 & f_1 & f_2 & f_3 & f_4 \\ 0 & 0 & 0 & 0 & g_1 & g_2 & g_3 & g_4 \\ \hline & & & & h_1 & k_1 & l_1 & m_1 \end{array}$$

is evidently equal to the merely rectangular bipartite

$$\begin{array}{cc|cccc} a_1 & a_2 & & & & \\ \hline b_1 & c_1 & d_1 & d_2 & d_3 & d_4 \\ b_2 & c_2 & e_1 & e_2 & e_3 & e_4 \\ b_3 & c_3 & f_1 & f_2 & f_3 & f_4 \\ \hline & & h_1 & k_1 & l_1 & m_1 \end{array}$$

and has only $2 \cdot 3 \cdot 4$ terms instead of $4 \cdot 4 \cdot 4$. Fewer zeros than twelve, be it also remarked, would make it assume the latter form; for, in a square-arrayed bipartite, if any line of any square array be a line of zeros, the line collinear with it in one of the adjacent squares may be made a line of zeros also.

40. A few examples will now be given of the occurrence of bipartite functions in mathematical investigations. These will partially indicate the bearing which the preceding theory has on cognate branches of analysis.

41. The elements of the determinant which is the product of m determinants of the nth order are bipartites of the degree-order (m, n).

Thus

$$\begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix} \times \begin{vmatrix} \alpha_1 & \alpha_2 & \alpha_3 \\ \beta_1 & \beta_2 & \beta_3 \\ \gamma_1 & \gamma_2 & \gamma_3 \end{vmatrix} = \begin{vmatrix} \dfrac{a_1\ a_2\ a_3}{\alpha_1\ \beta_1\ \gamma_1} & \dfrac{a_1\ a_2\ a_3}{\alpha_2\ \beta_2\ \gamma_2} & \dfrac{a_1\ a_2\ a_3}{\alpha_3\ \beta_3\ \gamma_3} \\ \dfrac{b_1\ b_2\ b_3}{\alpha_1\ \beta_1\ \gamma_1} & \dfrac{b_1\ b_2\ b_3}{\alpha_2\ \beta_2\ \gamma_2} & \dfrac{b_1\ b_2\ b_3}{\alpha_3\ \beta_3\ \gamma_3} \\ \dfrac{c_1\ c_2\ c_3}{\alpha_1\ \beta_1\ \gamma_1} & \dfrac{c_1\ c_2\ c_3}{\alpha_2\ \beta_2\ \gamma_2} & \dfrac{c_1\ c_2\ c_3}{\alpha_3\ \beta_3\ \gamma_3} \end{vmatrix},$$

and

$$\begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix} \times \begin{vmatrix} \alpha_1 & \alpha_2 & \alpha_3 \\ \beta_1 & \beta_2 & \beta_3 \\ \gamma_1 & \gamma_2 & \gamma_3 \end{vmatrix} \times \begin{vmatrix} x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \\ z_1 & z_2 & z_3 \end{vmatrix}$$

$$= \begin{vmatrix} \dfrac{a_1\ a_2\ a_3}{\alpha_1\ \beta_1\ \gamma_1}\ x_1 & \dfrac{a_1\ a_2\ a_3}{\alpha_1\ \beta_1\ \gamma_1}\ x_2 & \dfrac{a_1\ a_2\ a_3}{\alpha_1\ \beta_1\ \gamma_1}\ x_3 \\ \alpha_2\ \beta_2\ \gamma_2\ y_1 & \alpha_2\ \beta_2\ \gamma_2\ y_2 & \alpha_2\ \beta_2\ \gamma_2\ y_3 \\ \alpha_3\ \beta_3\ \gamma_3\ z_1 & \alpha_3\ \beta_3\ \gamma_3\ z_2 & \alpha_3\ \beta_3\ \gamma_3\ z_3 \\ \dfrac{b_1\ b_2\ b_3}{\alpha_1\ \beta_1\ \gamma_1}\ x_1 & \dfrac{b_1\ b_2\ b_3}{\alpha_1\ \beta_1\ \gamma_1}\ x_2 & \dfrac{b_1\ b_2\ b_3}{\alpha_1\ \beta_1\ \gamma_1}\ x_3 \\ \alpha_2\ \beta_2\ \gamma_2\ y_1 & \alpha_2\ \beta_2\ \gamma_2\ y_2 & \alpha_2\ \beta_2\ \gamma_2\ y_3 \\ \alpha_3\ \beta_3\ \gamma_3\ z_1 & \alpha_3\ \beta_3\ \gamma_3\ z_2 & \alpha_3\ \beta_3\ \gamma_3\ z_3 \\ \dfrac{c_1\ c_2\ c_3}{\alpha_1\ \beta_1\ \gamma_1}\ x_1 & \dfrac{c_1\ c_2\ c_3}{\alpha_1\ \beta_1\ \gamma_1}\ x_2 & \dfrac{c_1\ c_2\ c_3}{\alpha_1\ \beta_1\ \gamma_1}\ x_3 \\ \alpha_2\ \beta_2\ \gamma_2\ y_1 & \alpha_2\ \beta_2\ \gamma_2\ y_2 & \alpha_2\ \beta_2\ \gamma_2\ y_3 \\ \alpha_3\ \beta_3\ \gamma_3\ z_1 & \alpha_3\ \beta_3\ \gamma_3\ z_2 & \alpha_3\ \beta_3\ \gamma_3\ z_3 \end{vmatrix},$$

and the determinant which is the equivalent of

$$|a_1\ b_2\ c_3| \cdot |\alpha_1\ \beta_2\ \gamma_3| \cdot |x_1\ y_2\ z_3| \cdot |h_1\ k_2\ l_3|$$

has for its first element

$$\begin{vmatrix} \dfrac{a_1\ a_2\ a_3}{\alpha_1\ \beta_1\ \gamma_1} & \dfrac{h_1\ k_1\ l_1}{x_1\ x_2\ x_3} \\ \alpha_2\ \beta_2\ \gamma_2 & y_1\ y_2\ y_3 \\ \alpha_3\ \beta_3\ \gamma_3 & z_1\ z_2\ z_3 \end{vmatrix}.$$

The truth of any individual case of this follows at once from the preceding case by use of § 13.

42. The existence of a notation for the elements of a determinantal product and a knowledge of the properties of the elements facilitate very much the investigation of the laws of repeated determinantal multiplication. Some results of an investigation of this kind are intended to form the subject of a future paper: the matter is therefore not now entered on. Suffice it merely to draw attention to the fact that, when using the notation of bipartites, the *first element* of a determinantal product is all that need be given. For example, the last instance of § 41 is quite fully stated when we write

$$|a_1\ b_2\ c_3| \cdot |a_1\ \beta_2\ \gamma_3 \cdot |x_1\ y_2\ z_3| \cdot |h_1\ k_2\ l_3| = \left| \begin{array}{c|c} a_1\ a_2\ a_3 & h_1\ k_1\ l_1 \\ \hline a_1\ \beta_1\ \gamma_1 & x_1\ x_2\ x_3 \\ a_2\ \beta_2\ \gamma_2 & y_1\ y_2\ y_3 \\ a_3\ \beta_3\ \gamma_3 & z_1\ z_2\ z_3 \end{array} , \ldots\ldots \right|$$

The element given on the right hand side is the element of the place (1, 1), and the element of the place (r, s) is got by substituting for the 1st row a_1, a_2, a_3 the rth row of the same determinant, and for the 1st column h_1, k_1, l_1 the sth column of the same determinant.

43. This relation between bipartites and determinants is of considerable importance to the bipartite theory itself. Thus, we have seen (§ 23) that

$$\begin{array}{c|c} \begin{array}{ccc} m_1 & n_1 & r_1 \end{array} & \\ \hline \begin{array}{ccc|c} a_1 & a_2 & a_3 & a_1\ \beta_1\ \gamma_1 \\ b_1 & b_2 & b_3 & a_2\ \beta_2\ \gamma_2 \\ c_1 & c_2 & c_3 & a_3\ \beta_3\ \gamma_3 \end{array} & \begin{array}{c} x_1\ x_2\ x_3 \\ y_1\ y_2\ y_3 \\ z_1\ z_2\ z_3 \end{array} \end{array} \Bigg| \begin{array}{c} s_1 \\ s_2 \\ s_3 \end{array} = \begin{array}{ccc|c} m_1 & n_1 & r_1 & \\ \hline \mathrm{P}_1 & \mathrm{P}_2 & \mathrm{P}_3 & s_1 \\ \mathrm{Q}_1 & \mathrm{Q}_2 & \mathrm{Q}_3 & s_2 \\ \mathrm{R}_1 & \mathrm{R}_2 & \mathrm{R}_3 & s \end{array}$$

where

$$\mathrm{P}_1 = \begin{array}{ccc|c} x_1 & x_2 & x_3 & \\ \hline a_1 & \beta_1 & \gamma_1 & a_1 \\ a_2 & \beta_2 & \gamma_2 & b_1 \\ a_3 & \beta_3 & \gamma_3 & c_1 \end{array}, \qquad \mathrm{P}_2 = \begin{array}{ccc|c} x_1 & x_2 & x_3 & \\ \hline a_1 & \beta_1 & \gamma_1 & a_2 \\ a_2 & \beta_2 & \gamma_2 & b_2 \\ a_3 & \beta_3 & \gamma_3 & c_2 \end{array}, \qquad \mathrm{P}_3 = \begin{array}{ccc|c} x_1 & x_2 & x_3 & \\ \hline a_1 & \beta_1 & \gamma_1 & a_3 \\ a_2 & \beta_2 & \gamma_2 & b_3 \\ a_3 & \beta_3 & \gamma_3 & c_3 \end{array},$$

$$\mathrm{Q}_1 = \begin{array}{ccc|c} y_1 & y_2 & y_3 & \\ \hline a_1 & \beta_1 & \gamma_1 & a_1 \\ a_2 & \beta_2 & \gamma_2 & b_1 \\ a_3 & \beta_3 & \gamma_3 & c_1 \end{array}, \quad \&c.$$

But these bipartites are in order the elements of the determinant which is the

product of

$$|x_1\ y_2\ z_3|\ ,\ |\alpha_1\ \beta_2\ \gamma_3|\ ,\ |a_1\ b_2\ c_3|\ ;$$

hence, putting

$$|a_1\ b_2\ c_3| = \Delta_1\ ,\ |\alpha_1\ \beta_2\ \gamma_3| = \Delta_2\ ,\ |x_1\ y_2\ z_3| = \Delta_3\ ,$$

we may write the above identity in the form

$$\begin{array}{c|c|c} m_1\ n_1\ r_1 & & \\ \hline \Delta_1 & \Delta_2 & \\ & \Delta_3 \mid s_1 & \\ & \quad\ s_2 & \\ & \quad\ s_3 & \end{array} = \begin{array}{c|c} m_1\ n_1\ r_1 & \\ \hline & s_1 \\ \Delta_3\,\Delta_2\,\Delta_1 & s_2 \\ & s_3 \end{array}$$

and the like holds when there is *any* number of square arrays Δ_1, Δ_2, Δ_3, Δ_4, ...

As another instance, the theorem of § 27 may be taken, which may now stand thus—

$$\begin{array}{c|c|c} a_1\ a_2\ a_3 & \Delta_3 & \Delta_4 \\ \hline \Delta_1 & \Delta_2 & x_1\ y_1\ z_1 \end{array} = \begin{array}{c|c} a_1\ a_2\ a_3 & x_1\ y_1\ z_1 \\ \hline \Delta_2 \cdot \Delta_1 & \Delta_4 \cdot \Delta_3 \end{array}$$

but in the case of *every* theorem we have given regarding the condensation of bipartites a like simplification of expression is possible. The only points requiring attention are—(1) that, in forming the determinant of any square array, we must take for the first row that line of the square array which is contiguous with the bar separating it from the previous square array; (2) the initial and final lines of a bipartite are to be looked on as lines of a determinant whose other elements are all zeros.

44. Quantics are expressible as bipartites. Thus the binary cubic $(a\ b\ c\ d\&x\ y)^3$ is

$$\begin{array}{cc|c} x & y & \\ \hline a & b & x^2 \\ b & c & 2xy \\ c & d & y^2\ , \end{array}$$

and the ternary quadric

$$ax^2 + by^2 + cz^2 + 2dxy + 2exz + 2fyz$$

is

$$\begin{array}{ccc|c} x & y & z & \\ \hline a & d & e & x \\ d & b & f & y \\ e & f & c & z\ . \end{array}$$

45. A notable characteristic of the bipartite expression for a quadric is that it brings into evidence the *discriminant* of the quadric—the discriminant, in fact, being the determinant of the square array of the bipartite. This suggests

for examination how the matter of the *invariance* of the discriminant will look from the new point of view.

Instead of the special symmetric form which represents a quadric, let us rather take the quite general bipartite of the third degree

$$\begin{array}{ccc|c} x & y & z & \\ \hline a_1 & a_2 & a_3 & x' \\ b_1 & b_2 & b_3 & y' \\ c_1 & c_2 & c_3 & z' \end{array}$$

calling the determinant of it its square array Δ, and perform the *two* sets of substitutions

$$\left.\begin{aligned} x &= a\xi + a_2\eta + a_3\zeta \\ y &= \beta_1\xi + \beta_2\eta + \beta_3\zeta \\ z &= \gamma_1\xi + \gamma_2\eta + \gamma_3\zeta \end{aligned}\right\}$$

$$\left.\begin{aligned} x' &= m_1\xi' + m_2\eta' + m_3\zeta' \\ y' &= n_1\xi' + n_2\eta' + n_3\zeta' \\ z' &= r_1\xi' + r_2\eta' + r_3\zeta' \end{aligned}\right\}$$

calling the determinant of the first substitution Δ_1 and of the second Δ_2.

The mere substitution changes the bipartite into

$$\begin{array}{ccc|ccc|ccc|c} \alpha_1 & \alpha_2 & \alpha & \beta_1 & \beta_2 & \beta_3 & \gamma_1 & \gamma_2 & \gamma_3 & \\ \xi & \eta & \zeta & \xi & \eta & \zeta & \xi & \eta & \zeta & \\ \hline a_1 & & & a_2 & & & a_3 & & & \dfrac{m_1\ m_2\ m_3}{\xi'\ \eta'\ \zeta'} \\ b_1 & & & b_2 & & & b_3 & & & \dfrac{n_1\ n_2\ n_3}{\xi'\ \eta'\ \zeta'} \\ c_1 & & & c_2 & & & c_3 & & & \dfrac{r_1\ r_2\ r_3}{\xi'\ \eta'\ \zeta'} \end{array},$$

which

$$= \begin{array}{ccc|ccc|c} \xi & \eta & \zeta & & & & \\ \hline \alpha_1 & \alpha_2 & \alpha_3 & a_1 & b_1 & c_1 & \\ \beta_1 & \beta_2 & \beta_3 & a_2 & b_2 & c_2 & \\ \gamma_1 & \gamma_2 & \gamma_3 & a_3 & b_3 & c_3 & \\ & & & m_1 & n_1 & r_1 & \xi' \\ & & & m_2 & n_2 & r_2 & \eta' \\ & & & m_3 & n_3 & r_3 & \zeta' \end{array} \qquad (\S\ 22)$$

$$= \begin{array}{ccc|c} \xi & \eta & \zeta & \\ \hline & & & \xi' \\ \Delta_2\Delta\Delta_1 & & & \eta' \\ & & & \zeta' \end{array} \qquad (\S\ 43)$$

If, now, in this generalisation we make Δ axisymmetric, put $\xi, \eta, \zeta = \xi', \eta', \zeta'$, and consequently put $\Delta_2 \equiv \Delta_1$, we have the theorem that the discriminant of the quadric resulting from a linear substitution performed on a given quadric is equal to the discriminant of the original multiplied by the square of the modulus of substitution.*

* After the theory of this new class of functions had been worked out under a temporary designation of my own, I got the *Philosophical Transactions* for 1858, in consequence of a communication on another matter from Professor TAIT, in order to read Professor CAYLEY's Memoir on Matrices; and there found, immediately following the said memoir, another, "On the Automorphic Linear Transformation of a *Bipartite* Quadric Function." This quadric function I saw at the first glance was a member of the class I had been dealing with—viz., that of the *third* degree. This led me to discard the name I had been employing, and to adopt *bipartite* instead. Professor CAYLEY gives the above extension of the theorem regarding the invariance of the discriminant of a quadric, but without proof, and not as if looking at it from that point of view. I think, however, I am correct in saying that this is the only point in which my paper has been anticipated. Professor CAYLEY's notation for the bipartite we have used above is

$$\begin{pmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{pmatrix} \begin{matrix} \\ x\ y\ z \\ x'\ y'\ z' \end{matrix}$$

which does not, I think, bear on the face of it the exact nature of the two-sidedness of a bipartite of the third degree; that is to say, it does not imply, as

$$\begin{array}{ccc|c} x & y & z & \\ \hline a_1 & a_2 & a_3 & x' \\ b_1 & b_2 & b_3 & y' \\ c_1 & c_2 & c_3 & z' \end{array}$$

does, that the function is equal to

$$\text{either} \begin{cases} (a_1x' + b_1y' + c_1z')x \\ + (a_2x' + b_2y' + c_2z')y \\ + (a_3x' + b_3y' + c_3z')z \end{cases} \quad \text{or} \quad \begin{cases} (a_1x + a_2y + a_3z)x' \\ + (b_1x + b_2y + b_3z)y' \\ + (c_1x + c_2y + c_3z)z' \end{cases}.$$

It may be of interest, as another evidence of the usefulness of bipartites, to remark here that the "Memoir on Matrices" came opportunely for another reason. The new instrument I had got hold of seemed as if specially devised for dealing with matrices, and I immediately succeeded in proving CAYLEY's great theorem that, if M be a matrix, the equation—

$$\begin{vmatrix} a - \mathrm{M} & b & c \\ d & e - \mathrm{M} & f \\ g & h & k - \mathrm{M} \end{vmatrix} = 0$$

is satisfied by

$$\mathrm{M} = \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & k \end{pmatrix}.$$

This proof, with its accessories, has been communicated to the Mathematical Society of London.

46. A continuant is expressible as a bipartite.

Thus

$$\left|\begin{matrix} p & 1 \\ q & 1 \end{matrix}\right| = pq+1 = \begin{vmatrix} p & 1 \\ -1 & q \end{vmatrix},$$

$$\left|\begin{matrix} p & 1 \\ q & 1 \end{matrix}\right| r = pqr+p+r = \begin{vmatrix} p & 1 & . \\ -1 & q & 1 \\ . & -1 & r \end{vmatrix},$$

$$\left|\begin{matrix} p & 1 \\ q & 1 \end{matrix}\right| r \;\; 1 = pqrs+rs+pq+ps+1 = \begin{vmatrix} p & 1 & . & . \\ -1 & q & 1 & . \\ . & -1 & r & 1 \\ . & . & -1 & s \end{vmatrix};$$

$$\left|\begin{matrix} 1 \\ s \;\; 1 \end{matrix}\right|$$

and more generally

$$\left|\begin{matrix} p & 1 \\ q & b \end{matrix}\right| r \;\; 1 = \begin{vmatrix} p & b & . & . \\ -1 & q & c & . \\ . & -1 & r & d \\ . & . & -1 & s \end{vmatrix}.$$

$$\left|\begin{matrix} c \\ s \;\; d \end{matrix}\right|$$

This mode of expression seems more natural than the determinant form, a continuant consisting essentially of positive terms, if the elements be positive.

All the known theorems regarding continuants flow with the utmost readiness from the properties of bipartites.

XXVI.—*The* 364 *Unifilar Knots of Ten Crossings, Enumerated and Described.*

By Rev. Thomas P. Kirkman, M.A., F.R.S.

(Read July 20, 1885.)

1. The 119 subsolids (marked *ss*) and the 244 unsolids (marked *us*), of these unifilars are here arranged in lists according to their flaps. F_e is the number of flaps of e loops upon a knot; and the headings of the lists, as, *e.g.* $_{10}\mathbf{I}$, $F_2=1$, $F_1=3$, describe so far all the knots in the lists. Thus in $_{10}\mathbf{I}$ each has one 2-ple flap and three single ones. After the number in the list comes always the base on which the knot is constructed by the rules of my paper, XVII. in vol. xxxii. part ii. of the *Trans. R. S. E.*; and the reader who has that paper before him will find it easy to draw any knot on its base, nearly always there figured, by the first given flap, which is the leading one of the knot described; thus in $_{10}\mathbf{I}$ the first written flap is the double one, and in $_{10}\mathbf{P}$, $F_s=1$, $F_1=2$, it is the triple one. The leading flap of a subsolid is always followed by a colon.

It will be seen that no two subsolids nor unsolids have the same description. A flap AB, CD is generally given by its collaterals AB only; but the coverticals CD are added when required for distinguishing the knots from each other.

To me it appears that this tabulation of these knots will be more useful than the engraving of the figures; for the student who draws a 10-fold unifilar will hereby more readily satisfy himself that it is found or not found in my census, than if he had 364 knots projected before him, in the manner of the plates of my former paper. One solid knot makes up 364 unifilars.

2. I am indebted to Professor Tait for the detection of several bifilars which I had passed as unifilars, and for the addition of four to my list of unifilars,—namely, $_{10}\mathbf{B}$,21 ; $_{10}\mathbf{D}$,17 ; $_{10}\mathbf{I}$,30 ; and $_{10}\mathbf{L}$,8 ; and I may obtain from him farther contributions before he has performed on the figures all his surprising feats of twisting, which add a charm of conjuring to this curious and difficult inquiry.

The abbreviations which mark the symmetry are those used and explained in my paper above mentioned. My linear drawings of these unifilars of ten, as well as the more numerous figures of the unifilars of eleven crossings, will be found in the archives of the Royal Society of Edinburgh.

I have to acknowledge two omissions in my census of the knots of nine crossings. One is that of the bifilar $_9A_7^2$ referred to as a base under $_{10}\mathbf{I}$. This ought to have been formed in art. 55 by drawing from the point c the flap 63,44.

The other knot omitted is a unifilar ($_9A_7^2$) which should have been formed

by drawing in art. 53, in the base under 7, the flap 35,44. But no unifilar of ten crossings can be made on this ${}_9A\gamma^2$.

3. As Professor TAIT excludes all compound knots, *i.e.*, all that can be cut by a closed curve in two mid-edges only, the name of a fixed flap ought to be given to every flap whose deletion lays bare such a compound, *i.e.*, such a section through two edges only. As the deletion of such a flap is forbidden, so must be the drawing of it; and it cannot compete for the leadership with a flap drawn or about to be drawn.

A correction is to be made also in (2) of art. 27, which ought to stand thus:—

(2) If neither ϵ nor ϵ' be zoned polar, but be (*a*) one zoneless polar and the other epizonal, or (*b*) one zoneless polar and the other zonal, or (*c*) one epizonal and the other zonal, only one resulting configuration is possible: in all other cases, when neither ϵ nor ϵ' is zoned polar, and not both are asymmetric, two and only two configurations can and must be made by the above variation of posture of the charge.

In my plates in volume xxxii. part ii. a few errors require correction. In Pl. XLI., for ${}_9H$; 8, 10; read ${}_9H$; 4, 4, 10: in Pl. XLII., for ${}_9By$, 18; read ${}_9By$; 8, 10: for ${}_9Db$; 4, 14; read ${}_9Db$, 4, 4, 10: for ${}_9Ch$, 18; read ${}_9Ch$; 4, 14: for ${}_9Dk$, asym.; read ${}_9Dk$, Moz: after ${}_9Dl$ and after ${}_9Dm$ write 18. In Pl. XLIII. under ${}_9Gl$, for asym. write 2zo. Mox. Het.

Postscript, July 13, 1885.—This day I see for the first time that when the problem is to construct, not all the knots of n crossings, but only the non-compound unifilars, in which the tape passes over and under itself alternately at successive crossings, there is no need to discuss at all marginal dissections, nor marginal charges, nor any use of bifilar bases. This is shown as follows:—

Let K_n be any non-compound unifilar of n crossings alternately under and over all through the circuit. Going round the circle, plant at every mid-edge between two crossings a dot on the right of the thread.

Every flap will have two dots, both inside, or both outside, or one inside and the other outside of it. In the last case call the flap odd; in the others, even.

The following theorems are easily proved:—

Theorem A.—If K_n above defined has an even single flap (of one loop only), it can be reduced to an unifilar, solid or unsolid, of $n-1$ crossings by shrinking up that flap to a point.

Theorem B.—If K_n has an odd single flap, it can be reduced to an unifilar, solid or unsolid, of $n-2$ crossings by effacing the two edges and the two summits of that flap.

Theorem C.—If K has a double flap, of two loops, the two terminal con-

tiguous loops of a $(2+i)$-ple flap ($i \geqq 0$), the knot can be reduced to an unifilar, solid or unsolid, of $n-2$ crossings by shrinking up those two loops to a point.

It is evident that, if any clear definition of a leading flap and of a fixed flap be made and stuck to, the constructing converses (easily defined) of these three theorems must completely solve the following problem :—

The non-compound unifilars of $n-1$ and of $n-2$ crossings, alternately over and under, being given, to construct all the unifilars K_n above defined of n crossings, without risk of repeating a result in any posture, or of making a plurifil knot.

All that we have to do in reducing K_n is to do that at a leading or co-leading flap. All that we have to do in constructing K_n on a base, is to see that we do it by drawing or completing a flap which shall be the leader, or a co-leader on K_n. And we shall of course define that a plural flap leads any single one.

Thus, by theorem A, ${}_4A$ (*vide* Pl. XL. vol. xxxii. *Trans. R. S. E.*) reduces to ${}_8A$, on which it is regularly built by its even flap.

By theorem B, ${}_6A$ reduces to ${}_4A$, on which ${}_6A$ is properly constructed by its odd flap.

By theorem C, ${}_6F$ and ${}_6G$ reduce to ${}_4A$, on which by a double flap either is correctly formed.

By these little examples the constructing converses are plainly suggested.

This appears to make an end of the puzzle of unifilar knots whose crossings are all through alternately under and over, so far as their construction upon lower non-compound unifilars is desired, as a preparation for the curious transformations and reductions by twisting of LISTING and TAIT.

I fear that my distinction of subsolids and unsolids is of little value, as a subsolid can often be twisted into an unsolid, and *vice versâ*.

I have had theorems B and C for nearly a year. Had I obtained theorem A earlier, my tasks on the unifilars of 8, 9, 10, and 11 crossings would have been much easier, and under less risk of error.

The simplicity of the three theorems is provoking enough, as usual, after the labour spent with clumsier tools, which looked so much more learned.

${}_{10}A$.

$F_1 = 1$.

1. ss. ${}_8W$; 44,43 : Moz.
2. ss. ${}_8Ag$; 55,33 : 2zo. Mox. Het.
3. ss. ${}_8Ap$; 43,54 : asym.

${}_{10}B$

$F_1 = 2$.

1. ss. ${}_8A$; 63,63 : 2p. Mox. Het.
2. ss. „ 63,64 : 53 ; asym.
3. ss. ${}_8C$; 63,43 : 43 ; asym.
4. „ „ 63,53 : 43 ; „
5. „ „ 54,43 : 44 ; „
6. „ „ 53,43 : 2p. Mox. Het.
7. „ „ 43,53 : „
8. „ ${}_8D$; 53,53 : 43 ; asym.
9. „ „ 53,43 : 43 ; „
10. „ „ 43,53 : 43 : „
11. „ „ 43,43 : 2p. Mox. Het.
12. „ ${}_8E$; 54,33 : „
13. „ ${}_8M$; 44,43 : 2zo. Mox. Het.

14. ss. $_8$U; 54,33: 44; asym.
15. „ $_8$W; 43,54: 43; „
16. „ „ 53,44: 43; „
17. „ „ 44,44: 2p. Mox. Het.
18. „ „ 43,54: Moz.
19. „ „ 43,44: 2p. Mox. Het.
20. „ „ 53,54: „
21. „ „ 53,54: Moz.
22. „ $_8$A*t*; 64: Moz.
23. us. $_8$A; 53,63; 33; asym.
24. „ $_8$B; 44; 33; „
25. „ $_8$C; 43; 33; „
26. „ „ 53,43; 33; „
27. „ $_8$D; 43; 33; „
28. „ $_8$T; 64; 33; „
29. „ $_8$X; 34; 33; „
30. „ $_8$A*g*; 73; 33; Moz.
31. „ $_8$A*h*; 53; 33; „
32. „ $_7$C; 63; 53; asym.
33. „ „ 73; 73; „
34. „ $_7$D; 63; 43; „
35. „ „ 53; 43; „
36. „ $_4$A; 53; 53; 2p. Mox. Het.

$_{10}$C.

$F_1 = 3$.

1. ss. $_8$A; 63,64: 64; 63; asym.
2. „ $_8$C; 63,54: 63; 53; „
3. „ „ 63,54: 63; 54; „
4. „ „ 54,55: 53; 53; „
5. „ „ 53,64: 34,35; 54; „
6. „ „ 43,64: 64; 43; „
7. „ $_8$D; 53,55: 53; 53; „
8. „ „ 53,54: 53; 53; „
9. „ „ 53,54: 54; 43; „
10. „ „ 53,54: 53; 43,44; „
11. „ „ 43,54: „
12. „ $_8$E; 63,43: 53; 53; „
13. „ „ 63: 54; 53; „
14. „ „ 54,53: 55; 53; „
15. „ $_8$G; 63,53: 53; 43; „
16. „ „ 63: 44; 43; „
17. „ „ 53: 64; 43; „
18. „ „ 53: 44; 43; „
19. „ „ 44: 54; 43; „
20. ss. $_8$G; 54,43: 44; 43; asym.
21. „ „ 53,34: 54; 43; „
22. „ $_8$I; 54: 54; 53; „
23. „ „ 53: 53; 43,55; „
24. „ $_8$P; 54,53: 44; 43; „
25. „ $_8$Q; 53: 53; 43,54; „
26. „ $_8$R; 55,43: 54,43; 53,44; „
27. „ „ 55,53: 53; 53; Moz.
28. „ $_8$S; 63: 63; 53; „
29. „ „ 54,53: 53; 53; asym.
30. „ „ 63,43: 63; 53; „
31. „ $_8$V; 63,53: 63; 44; Moz.
32. „ „ 63,43: 63; 44; 2p. Mox. Het.
33. „ „ 54: 53; 44; asym.
34. „ $_8$X; 53,54: 53; 43,55; „
35. „ „ 63,44: 43; 43; „
36. „ „ 63,54: 53; 43; „
37. „ „ 53,44: 43; 43; „
38. „ „ 54,44: 44; 43; „
39. „ $_8$A*a*; 54: 54; 43,55; „
40. „ $_8$A*c*; 64,43: 65; 43; „
41. „ $_8$A*d*; 64,43: 63; 43; „
42. „ „ 74,43: 73; 73; „
43. „ $_8$A*e*; 74,33: 73; 73; „
44. „ $_8$A*d*; 65,33: 63; 53; „
45. „ „ 55,43: 53; 43; „
46. „ $_8$A*f*; 55,33: 53; 43; „
47. „ $_8$A*f*; 64,33: 63; 43; „
48. „ $_8$A*g*; 73: 73; 73; Moz.
49. „ „ 55,44: 53; 53; 2p. Mox. Het.
50. „ $_5$A*h*; 63,54: 63; 53; asym.
51. „ „ 54,44: 53; 53; „
52. us. $_6$F; 75; 33; 33; asym.
53. ss. $_8$A*t*; 55,43: 54,33; 53,44 „
54. „ $_8$A*u*; 54 54; 43,44; „
55. „ $_8$A*v*; 64,33: 65; 43; „
56. „ $_8$B*a*; 64: 64; 43; „
57. us, $_8$E; 63,53; 54; 33; asym
58. „ $_8$F; 63; 44; 33; „
59. „ $_8$C; 54; 43; 33; „
60. „ $_8$I; 54; 33; 33; „
61. „ „ 53; 53; 33; „
62. „ $_8$P; 53; 43; 33; „
63. „ $_8$Q; 44; 43; 33; „

64. us. $_8$R; 73; 73; 33; Moz.
65. „ „ 74; 73; 33; asym.
66. „ $_8$S; 65; 53; 33; „
67. „ „ 63; 63; 33; 2p. Mox. Het.
68. „ $_8$U; 63,43; 54; 33; asym.
69. „ „ 55; 53; 33; „
70. „ $_8$A*c*; 65; 63; 33; „
71. „ $_7$E; 63; 63; 43; „
72. „ „ 54; 53; 53; „
73. „ „ 64; 53; 43; „
74. „ „ 73; 73; 43; „
75. „ „ 63; 54; 53; „
76. „ „ 74; 73; 43; „
77. „ $_6$A; 63; 44; 43; „
78. „ $_6$C; 53; 33; 33; 2zo. Mox. Het.
79. „ $_6$A; 53; 44; 43; „

$_{10}$D.

$F_1=4$.

1. ss. $_8$E; 63: 64; 54; 53; asym.
2. „ „ 54: 54; 54; 54; 2p. Mox. Het.
3. „ $_8$G; 63: 64; 53; 44; asym.
4. „ „ 53; 55; 53; 53; „
5. „ „ 54,55: 54; 53; 53; „
6. „ $_8$I; 63: 63; 54; 54; „
7. „ „ 63: 63; 55; 53; „
8. „ „ 54,54: 54; 53; 53; 2p. Mox. Het.
9. „ $_8$L; 63: 64; 55; 53; asym.
10. „ $_8$P; 54: 53; 53; 44; „
11. „ „ 63: 63; 54; 43; „
12. „ $_8$Q; 53: 53; 44; 44; 2p. Mox. Het.
13. „ „ 53: 54; 44; 43; asym.
14. „ $_8$V; 63: 65; 54; 53; „
15. „ „ 63: 65; 54; 43; „
16. us. „ 65: 55; 43; 33; „
17. ss. $_8$P; 53: 54; 53; 43; „
18. „ $_8$Y; 54: 54; 53; 43; „
19. „ $_8$A*b*; 65: 64; 53; 43; „
20. „ 74: 74; 73; 43; „
21. „ $_8$A*c*; 73: 75; 73; 43; „
22. „ „ 55: 55; 53; 43; „
23. „ $_8$A*e*; 64: 64; 63; 63; 2p. Mox. Het.
24. ss. $_8$A*f*; 64: 63; 55; 53; asym.
25. „ $_8$A*l*; 64: 64; 63; 63; „
26. „ $_8$A*x*; 63: 66; 63; 44; 2p. Mox. Het.
27. „ „ 73: 73; 75; 44; Moz.
28. „ „ 55: 55; 53; 53; asym.
29. „ „ 63: 66; 63; 43; „
30. „ $_8$A*w*; 55: 54; 54; 43; „
31. „ „ 73: 74; 74; 53; „
32. „ $_8$A*x*; 53: 55; 55; 53; 2p. Mox. Het.
33. „ „ 54: 54; 43; 43; Moz.
34. „ $_8$B*f*; 65: 64; 53; 53; asym.
35. „ $_8$B*j*; 55: 55; 55; 44; Moz.
36. „ $_8$B*m*; 55: 54; 54; 44; 2p. Mox. Het.
37. us. $_8$A*w*; 75,43; 74; 43; 33; asym.
38. „ „ 75,33; 74; 43; 33; „
39. „ $_8$A*z*; 65,33; 64; 43; 33; „
40. „ „ 65,34; 64; 43; 33; „
41. „ $_8$B*j*; 76; 76; 43; 33; „
42. „ $_7$L; 66; 63; 63; 44; „
43. „ „ 75; 73; 73; 44; „
44. „ $_6$G; 66; 66; 33; 33; 2zo. Mox. Het.
45. „ $_6$H; 55; 55; 33; 33; „
46. ss. $_8$A*j*; 64: 63; 54; 43; asym.
47. „ „ 55,44: 54; 53; 43; „

$_{10}$E.

$F_1=5$.

1. ss. $_8$A*n*; 55: 65 65; 43; 43; 2p. Mox. Het.
2. „ $_8$B*k*; 55: 65 65; 55; 53; Moz.
3. us. $_8$B*l*; 76: 76 73; 44; 33; „

$_{10}$F.

$F_2=1$; $F_1=0$.

1. us. $_9$B; 55; Moz.
2. „ $_9$F; 65; „

$_{10}$G.

$F_2=1$; $F_1=1$.

1. us. $_9$L; 64; 64; asym.
2. „ $_9$V; 54; 44; „

3.	us.	$_9Ac$; 54; 54,33;	asym.
4.	„	$_9Ap$; 54; 54,35;	„
5.	„	$_9Br$; 74; 33;	„
6.	„	„ 44; 63;	„
7.	„	$_9Bs$; 54; 33;	„
8.	„	„ 44; 43;	„
9.	„	$_9By$; 44; 53;	Moz.
10.	„	„ 64; 33;	„
11.	„	$_9Ck$; 64; 43;	asym.
12.	„	$_9Cl$; 74; 43;	„

$_{10}$H.

$F_2=1$; $F_1=2$.

1.	us.	$_9M$; 54; 55; 53;	asym.
2.	„	„ 65; 63; 53;	„
3.	„	$_9N$; 74; 73; 73;	Moz.
4.	„	$_9R$; 54; 53; 53;	asym.
5.	„	„ 64,54; 63; 43;	„
6.	„	$_9S$; 64; 53; 44;	„
7.	„	$_9T$; 64,44; 63; 43;	„
8.	„	„ 54; 53; 53;	Moz.
9.	„	$_9V$; 64; 54; 43;	asym.
10.	„	„ 54; 54; 53;	„
11.	„	$_9W$; 55; 53; 43;	„
12.	„	„ 54,54; 54,54; 43;	„
13.	„	$_9X$; 55; 44; 44;	„
14.	„	$_9Aa$; 54,54; 54,44; 43;	„
15.	„	„ 54,43; 54; 43;	„
16.	„	$_9Ac$; 54; 64; 63;	„
17.	„	„ 74; 74; 43;	„
18.	„	$_9Ad$; 74; 74; 53,74;	„
19.	„	„ 64; 64; 63;	„
20.	„	$_9Af$; 64; 64; 53;	„
21.	„	$_9Ag$; 65; 64; 44,54;	„
22.	„	„ 55; 54; 54;	Moz.
23.	„	$_9An$; 64; 44; 43;	asym.
24.	„	$_9Ar$; 64; 64; 43;	„
25.	„	$_9As$; 74; 74; 43;	„
26	„	$_9At$; 64; 65; 43;	„
27	„	$_9Au$; 74; 74; 53,73;	„
28.	„	$_9Ax$; 64; 65; 53;	„
29	„	$_9Ba$; 55; 54; 54;	„
30	„	$_9Ba$; 65; 64; 44,34;	„
31.	„	$_9Bc$; 65; 64; 44,63;	„
32.	„	„ 55; 54; 54;	Moz.
33.	us.	$_9Bk$; 66; 65; 65;	Moz.
34.	„	$_9Bl$; 65; 65; 54;	asym.
35.	„	$_9Bm$; 75; 74; 74;	Moz.
36.	„	$_9Bp$; 65; 53; 33;	„
37.	„	„ 54; 55; 33;	„
38.	„	$_9Bq$; 66; 53; 33;	„
39.	„	$_9Bt$; 54; 63; 33;	asym.
40.	„	„ 44; 63; 43;	„
41.	„	$_9Bu$; 75; 43; 33;	„
42.	„	$_9Bx$; 44; 54; 53;	„
43.	„	„ 65; 63; 33;	„
44.	„	„ 64; 64; 33;	„
45.	„	$_9Bw$; 44; 54; 43;	„
46.	„	„ 65; 43; 33;	„
47.	„	$_9Bx$; 55; 54; 33;	„
48.	„	$_9Cd$; 44; 65; 43;	„
49.	„	„ 76,43; 43; 33;	„
50.	„	„ 54; 65; 33;	„
51.	„	$_9Ce$; 76,33; 43; 33;	„
52.	„	„ 44; 65; 43;	„
53.	„	„ 54; 65; 33;	„
54.	„	$_9Cm$; 74; 73,33; 44;	Moz.
55.	„	„ 74; 73,44; 44;	„
56.	„	$_9Cn$; 64,44; 53; 44;	„
57.	„	„ 64,33; 53, 44;	„
58.	„	$_9Cp$; 54; 63; 53;	asym.
59.	„	$_9Dk$; 44; 55; 33;	Moz.
60.	„	„ 66; 33; 33;	„
61.	„	$_9Dl$; 84; 85; 83;	asym.
62.	„	$_9Dm$; 74; 76; 63;	„

$_{10}$I.

$F_2=1$; $F_1=3$.

1.	us.	$_9E$; 64; 65; 53; 53;	asym.
2.	„	$_9Ah$; 65; 63; 54; 44;	„
3.	„	„ 55; 55; 53; 44;	„
4.	„	$_9Ai$; 65; 64; 53; 53;	„
5.	„	„ 54; 55; 54; 53;	„
6.	„	$_9Ak$; 75; 74; 43; 43;	„
7.	„	$_9Al$; 75; 74; 53; 53;	„
8.	„	$_9Aw$; 66; 63; 63; 54;	„
9.	„	„ 64; 65; 54; 53,54;	„
10.	„	„ 64; 65; 54; 53,53;	„
11.	„	$_9Ax$; 74; 74; 73; 54,44;	„
12.	„	„ 74; 74; 73; 54,43;	„

13. us. ${}_9A\varepsilon$; 75; 73; 73; 54; asym.
14. „ ${}_9A\varsigma$; 65; 65; 43; 43; „
15. „ „ 54; 55; 54; 43; „
16. „ „ 65; 64; 43; 43; „
17. „ ${}_9Be$; 55; 55; 54; 53; „
18. „ „ 65; 63; 54; 54; „
19. „ ${}_9Bf$; 54; 54; 65; 63; „
20. „ „ 55; 53; 65; 63; „
21. „ ${}_9Bg$; 65; 65; 53; 53; „
22. „ „ 66; 64; 53; 53; „
23. „ „ 64; 63; 55; 54; „
24. „ ${}_9Cf$; 74; 75; 44; 33; „
25. „ „ 76; 73; 44; 33; „
26. „ „ 55; 65; 63; 33; „
27. „ ${}_9Ch$; 75; 76; 65; 33; „
28. „ ${}_9Cj$; 44; 76; 76; 73; „
29. „ „ 87; 87; 83; 33; „
30 „ ${}_9A\varsigma^2$; 54; 65; 63; 43; „

${}_{10}$J.

$F_2=2$; $F_1=0$.

1. us. ${}_8$A; 64; 64; 2*p*. Mox. Het.
2. „ ${}_8$C; 64; 54; asym.
3. „ ${}_8$D; 54; 54; 2p. Mox. Het.
4. „ ${}_8$X; 54; 44; asym.

${}_{10}$K.

$F_2=2$; $F_1=1$.

1. us. ${}_8$E; 74; 74; 44; asym.
2. „ „ 65; 64; 63,65; „
3. „ „ 65; 64; 63,63; „
4. „ ${}_8$F; 64; 55; 63; „
5. „ ${}_8$G; 65; 54; 43,63; „
6. „ „ 65; 54; 43,65; „
7. „ „ 54; 54; 54; „
8. „ ${}_8$I; 65; 64; 53; „
9. „ ${}_8$P; 54; 54; 53; Moz.
10. „ ${}_8$Q; 55; 54; 43; asym.
11. „ ${}_8$R; 85; 84; 83; „
12. „ ${}_8$S; 76; 74; 63; „
13. „ ${}_8$U; 64; 55; 65; „
14. „ „ 66; 65; 63; „
15. „ „ 75; 74; 54; „
16. us. ${}_8$Y; 55; 44; 53; Moz.
17 „ ${}_8$Z; 54; 44; 53; „
18. „ „ 64; 64; 33; 2zo. Mox. Het.
19. „ ${}_8A\alpha$; 65; 44; 55; Moz.
20. „ ${}_8A\varepsilon$; 76; 44; 73; asym.
21. „ „ 74; 44; 75; „

${}_{10}$L.

$F_2=2$; $F_1=2$.

1. us. ${}_8$J; 55; 55; 54; 54; 2p. Mox. Het.
2. „ ${}_8$K; 65; 64; 53; 55; Moz.
3. „ „ 54; 54; 55; 55; 2zo. Mox. Het.
4. „ ${}_8$L; 65; 65; 63; 63; 2p. Mox. Het.
5. „ ${}_8$V; 65; 54; 55; 65; asym.
6. „ „ 76; 75; 65; 43; „
7. „ ${}_8A\nu$; 77; 44; 77; 33; Moz.
8. „ ${}_8$L; 75; 74; 54; 53; asym.

${}_{10}$M.

$F_2=3$; $F_1=0$.

1. us. ${}_7$E; 75; 74; 54; asym.
2. „ ${}_7$F; 65; 65; 54; Moz.

${}_{10}$N.

$F_3=1$; $F_1=1$.

1. us. ${}_8$B; 66; 44; asym.
2. „ ${}_8$T; 76; 74; „
3. „ ${}_8$X; 65; 33; „
4. „ ${}_8$X; 55; 34; „
5. „ ${}_8A\mu$; 55; 33; 2zo. Mox. Het.

${}_{10}$P.

$F_3=1$; $F_1=2$.

1. us. ${}_8$E; 75; 73,45; 54; asym.
2. „ „ 75; 73,53; 54; „
3. „ „ 76; 53; 53; „
4. „ ${}_8$F; 66; 53; 53; Moz.

5. us. $_8$F; 75; 73; 44; asym.
6. „ $_8$G; 76; 43; 43; „
7. „ „ 65,54; 54; 43; „
8. „ „ 65,53; 54; 43; „
9. „ $_8$Q; 66; 43; 43; 2p. Mox. Het.
10. „ „ 65; 44; 43; asym.
11. „ $_8$Y; 66; 53; 33; Moz
12. „ „ 55; 53; 44; „
13. „ „ 75; 44; 33; „
14. „ $_8$Ac; 85; 85; 33; asym.
15. „ „ 87; 83; 33; „
16. „ „ 55; 65; 63; „

$_{10}$Q.

$F_3=1$; $F_1=3$.

1. us. $_8$L; 76; 73; 54; 53; asym.
2. „ „ 75; 74; 54; 53;

$_{10}$R.

$F_3=1$; $F_2=1$; $F_1=0$.

1. us. $_7$C; 85; 84; asym.
2. „ $_7$D; 65; 54; „
3. „ $_7$G; 75; 44; „

$_{10}$S.

$F_3=1$; $F_2=1$; $F_1=1$.

1. us. $_7$E; 76; 54; 73; asym.
2. „ „ 85; 85; 43; „
3. „ „ 75; 54; 74; „
4. „ „ 65; 65; 63; „
5. „ $_7$F; 76; 75; 43; „
6. „ „ 65; 55; 54; „
7. „ $_7$J; 77; 44; 33; Moz.
8. „ „ 55; 44; 55; „

$_{10}$T.

$F_3=1$; $F_2=2$; $F_1=0$.

1. us. $_6$B; 75; 74; 55; Moz.
2. „ $_6$C; 77; 76; 76; 2zo. Mox. Het.

$_{10}$U.

$F_3=2$.

1. us. $_6$A; 65; 65; 2p. Mox. Het.

$_{10}$V.

$F_4=1$; $F_1=1$.

1. us. $_7$C; 86; 83; asym.
2. „ $_7$D; 76; 43; „
3. „ $_7$G; 66; 53; Moz.

$_{10}$W.

$F_4=1$; $F_1=2$.

1. us. $_7$E; 87; 83; 43; asym.
2. „ „ 76; 54; 53; „
3. „ $_7$F; 77; 74; 43; „
4. „ $_7$J; 66; 55; 33; Moz.

$_{10}$X.

$F_4=1$; $F_2=1$

1. us. $_6$A; 76; 54; asym.

$_{10}$Y.

$F_4=1$; $F_2=1$; $F_1=1$

1. us. $_6$B; 77; 54; 53; Moz.
2. „ $_6$C; 87; 85; 75; „
3. „ $_6$B; 76; 73; 55; „

$_{10}$Z.

$F_4=1$; $F_3=1$.

1. us. $_5$A; 96; 95; Moz.

$_{10}\Delta$.

$F_5=1$; $F_1=1$.

1. us. $_6$A; 87; 43; asym.

$_{10}\Theta$.

$F_5=1$; $F_2=1$.

1. us. $_5$A; 97; 94; Moz.

$_{10}\Sigma$.

$F_6=1$; $F_1=1$.

1. us. $_4$A; 98; 93; Moz.

$_{10}\Xi$.

$F_5=1$; $F_3=1$.

1. us. $_1$A; 77; 55; 2zo. Mox. Het.

$_{10}\Phi$.

$F_7=1$; $F_1=1$.

1. us. $_4$A; 99; 33; 2zo. Mox. Het.

Finally, there is one solid unifilar knot, the $_{10}$B described in art. 68 of my memoir above referred to. In that article the quadrifilar (4466) $_{10}$A is wrongly designated a zoned triaxine; that $_{10}$A is a 4-zoned monarchaxine heterozone.

NOTE.—Two Appendices to this paper will be found in the *Proceedings of the Royal Society of Edinburgh*, vol. xiii. p. 359.

XXVII.—*On Knots.* Part III. By Professor TAIT. (Plates LXXIX., LXXX., and LXXXI.)

(Chapter I. read June 1st, Chapter II. July 20th, 1885. *One change, small but important, was made during printing. It is described at the end of the paper.*)

The following additional remarks are the outcome of my study of the polyhedral data for tenfold knottiness, which I received from Mr KIRKMAN on the 26th of last January. My main object was, as in the first chapter of Part II., to determine the number of different types; as well as the number of essentially different forms which each type can assume, as distinguished from mere deformations due to the mode of projection.

This study has been a somewhat protracted one, in consequence (1) of the great number of tenfold knots; (2) of the very considerable number of distortions of several of the types, many of which are essentially distinct while others present themselves in pairs differing by mere *reversion;* and especially (3) of the fact that the polyhedral method often presents some of the distinct forms of one and the same type projected from essentially different points of view (of which, in the present case, there are sometimes twelve in all). Reason (3) depends on the fact that KIRKMAN'S method occasionally builds up various forms of one type on different bases of a lower order, and it really involves additional labour only; but great care is requisite to avoid confusion as regards (2), and in consequence I may not have fully reduced the final number of distinct types. [At the end of this paper I shall give a simple illustration of the nature of this special difficulty.]

The fact that I was dealing with knottiness of an even order induced me to commence the testing of the materials at my command by picking out the Amphicheirals. This led to some new considerations of a very singular nature, which are treated in the first of the following chapters. The second deals with the tenfolds as a whole.

I. *Various Orders and Classes of Amphicheirals.*

1. As one form of check on KIRKMAN'S results, I sought for an independent method of forming all the amphicheirals of a given order. But, as will be seen below, we must be careful in this matter, which is not so simple as I first thought. I therefore commence by recalling the original definition of an amphicheiral.

In § 17 of my first paper I introduced it thus:—

An amphicheiral knot is one which can be deformed into its own perversion.

The word "deformed" was here used in the sense of alteration of form by mere change of point of view, or mode of projection; a process which leaves the number of corners in each mesh, and the *relative* positions of the various meshes, unchanged. This definition implies that the right and left handed meshes are similar in pairs and similarly situated in *congruent* groups; and it will be adhered to for the present, though we shall afterwards find that there are at least three other senses in which a knot may be called amphicheiral, and shall thus be led to speak of different *orders* and *classes* of amphicheirals. The above definition will then be considered to belong to amphicheirals of the *First Order* and *First Class.*

2. Suppose an amphicheiral knot to be constructed in cord, and extended over the surface of a sphere which swells out when necessary so as to keep the cord tight like the netting on a gazogene. Let its various laps be displaced until the several corresponding pairs of right and left handed meshes are made equal as well as similar. Trace its position on the sphere. Now suppose it to become rigid, and move it about on the surface of the sphere. We can again bring it to coincide with its former trace, but in such a way that each left-handed compartment now stands where the corresponding right-handed one was, and each right-handed where its corresponding left-handed was. Now such a displacement, as we know, can always be effected by a finite rotation about a diameter of the sphere as axis.

This axis, of course, cannot terminate (at either end) inside a mesh, else that compartment could not be shifted by the rotation to the original position of the corresponding one of the other kind. Hence either end of the axis must be at a crossing, or midway on the lap of cord passing through two adjoining crossings. A little consideration shows that if one end be at a crossing the other also must be at a crossing, and the whole must be a link. This is easily seen from the fact that, if one end of the axis be at a crossing, the four meshes which meet there must each exactly fit that next it when the whole is turned through a right angle; and the series which immediately surrounds these must possess a similar property, &c., &c. Thus the whole spherical surface must be covered with a pattern which consists of four equal and similar parts, each of which takes the place of the preceding one at every quarter of a rotation about the axis. And four laps of the string must therefore proceed all in the same way from one end of the axis to the other; since, if we can trace one lap of the string continuously from one crossing to the other, exactly the same must be true of the other three. [Of course, if the string cannot be traced from one crossing to the other, there must be two separate strings at least.]

Hence, for a true knot, both ends of the axis must be the middle points of laps; and therefore—

There must be two laps, at least, in every amphicheiral knot, each of which is common to a pair of corresponding right and left handed meshes; and when the whole is symmetrically stretched over a sphere the middle points of these laps are at opposite ends of a diameter.

3. With regard to the middle point of either of these laps, the various pairs of corresponding right and left handed meshes are situated at equal arcual distances measured in opposite directions on the same great circle. Hence if the whole be opened up at the middle point of either of these laps and projected on a plane symmetrically about the middle point of the other, the halves into which the plane figure is divided by any straight line passing through the latter point are congruent figures applied on opposite sides of that line as base; the point being, as it were, a *centre*. There are, thus, at least two ways of opening up any amphicheiral knot so as to exhibit this species of quasi-symmetry.

What precedes is on the supposition that the system of right, or of left, handed meshes can be applied to itself *in one way only*. If there be, as happens in some specially symmetrical cases, more than one way of doing this, there is a corresponding increase in the number of pairs of common laps, as defined in the preceding section.

It has also been assumed above that, on the sphere, the systems of right and left handed meshes are not only similar but *congruent*. The question of the possible existence of knots in which the system of right hand meshes shall be the *reversion* of the left hand system will be considered later.

4. We now obtain a perfectly general, though of course in one sense tentative, method of constructing amphicheirals of any order. Think of the result of § 3 as to the congruency of the halves of the knot when opened at either of the pair of corresponding laps. As a continuous line necessarily cuts the projection of a complete knot in an *even* number of points, the half figure which is to be drawn on one side of the common base must meet it in an *odd* number of points because one lap has been opened. Let these be called, in order, A, B, C, &c. Then, to form the half figure, these points must be joined in pairs, the odd one forming one end of the line whose other terminal is at the broken lap. These joining lines, and that with the free end, must be made to intersect one another in a number of points equal to *half* the knottiness of the amphicheirals sought. Every mode of doing this gives a figure which, when its congruent has been applied on the other side of the base, possesses the amphicheiral quasi-symmetry above described.

5. To ensure that the figure shall be a knot, and not a link or a set of detached figures, the following precautions are necessary. If A′, B′, C′, &c.,

in the congruent figure correspond to A, B, C, &c., in the original, they will be adjusted to one another as follows. (The case of five is taken as being sufficient to show the general principle.)

A B C D E
E′ D′ C′ B′ A′.

Now if B be joined with D, however the joining line be linked with the others, B′ will be joined to D′; and these parts will form, together, one closed circuit, so that the figure is not a knot. Similarly if A and E be joined. Similarly if A be joined to B, and *also* D to E. If C be the terminal of the free lap, so will C′; and again we have a figure consisting of more than one string.

It will be observed that the common characteristic of these excepted cases is that each possesses at least partial symmetry in the mode in which points to be joined are selected from the group. Hence the rule for selection is simply to *avoid every trace of symmetry.*

Even when this is done the final result may be a composite knot, *i.e.*, two or more separate knots on the same string. These can be detected and removed at once, so that it is not necessary to lay down rules for preventing their occurrence.

Repetitions of the same form from different points of view form the only really troublesome part of this process. These are inevitable, as we see at once from the fact that there may be several essentially different ways of cutting the complete quasi-symmetrical figure into congruent halves by lines meeting it in the *same* odd number of points. But it may also often be cut by one such line in one odd number of points and by another in a different odd number.

Still, with all these inherent drawbacks, the method is applicable without much labour to the tenfold amphicheirals; and it fully answered my purpose.

6. I had proceeded but a short way with the application of this method when I found that *there may be more than one distinct amphicheiral belonging to the same type.*

One example of this had been already given in § 48 of Part I. while I was dealing with amphicheirals, and again in Part II. in my census of eightfolds (Type V.), but I had carelessly passed it over as a special peculiarity probably due to the fact that the knot in question, though not composite, was constructed of portions each of which possessed, all but complete, the outline of the fourfold amphicheiral. From the point of view taken in § 4 above, however, the reason of the property is evident. For if the half knot, when the extremities of the strings are all held fixed, be capable of a distortion which shall change the relative positions of some of its meshes or the numbers of their corners,

the same can of course be done with the congruent half. The whole preserves its type, and is still amphicheiral, but it becomes an essentially distinct form.

It will be seen that there is one type of tenfolds which has four different amphicheiral forms; another contains three; while there are four types each with two forms. The remaining seven amphicheiral types are either unique forms or have no amphicheiral distortion.

7. We are now prepared for one extension of the definition of an amphicheiral given in § 1 above. But we prefer to establish a new and independent definition:—thus

An amphicheiral knot of the First Order and Second Class is one which can be distorted into its own perversion.

Under this definition every distortion of an amphicheiral knot is included, even although it be such that its right and left handed meshes do not correspond to one another in pairs. For, whatever be the distortion, and whatever parts of the knot be affected by it, an exactly similar distortion might have been applied to the congruent parts of the original amphicheiral. These two distorted forms are, of course, capable of being distorted one into the other:—and that other is its perversion.

Every amphicheiral knot of the first order and second class corresponds to, and can be distorted into, at least one of the first class:—but the converse is not necessarily true.

8. Whether there are other classes of amphicheirals of the first order besides these I do not yet know. I have made attempts to construct a specimen of a supposed Third Class which should have the property of being changed into its own perversion by the twisting of a *single*, limited, portion, while the result could *not* be obtained by any simpler method. Such forms, if they exist, must in general be incapable of distortion into amphicheirals of either the first or the second class. This search has been fruitless. Among the requirements which it introduces, is the necessity for an ordinary amphicheiral in which *two* pairs of corresponding right and left hand meshes shall have one common corner; a condition which does not seem to be satisfied except by the simplest (amphicheiral) link, in which indeed it *must* be satisfied, as there are but four compartments in all. But this gives no satisfactory solution.

9. We may now take up the curious question raised in the last paragraph of § 3 above.

A simple method of producing arrangements in which the group of left-handed meshes is similar to, but not congruent with, that of the right-handed follows at once from the fact that, if one end of a diameter of a sphere trace a figure of any kind, the other end traces a similar and equal but (except in special cases of symmetry) non-congruent figure. These figures can, if we

choose, be taken so as together to form one closed curve; and this, *along with a great circle of the sphere*, forms a link of two cords possessing the required property. On the plane we can carry out this construction by describing any figure within a circle, along with its inverse as regards the circle but on the opposite side of the centre; and arranging so that these may join into a continuous curve linked with the circle. But this arrangement *remains a link* when we unite the new curve with the circle by so introducing new meshes as to leave the whole possessed of the required property.

Or, we may trace any curve on a hemisphere, and its image (in the common base) on the other hemisphere. These, together with the great circle separating the hemispheres, give another link solution.

It is clear, from the essentially limited nature of the spherical surface, that these two methods give the only possible solutions of the problem:—*i.e.*, when the corresponding right and left handed meshes required by the conditions are made equal in pairs, the lines joining similarly situated points in them must either meet in one point (which, of course, must be the centre of the sphere), or they must be parallel.

10. As I did not at once see how to obtain solutions corresponding to *unifilar* knots by means of either of these methods, I asked Mr KIRKMAN whether he knew of a polyhedron which possessed the requisite property. The first he suggested to me corresponded, as I easily found, to a trifilar which belongs to the results of the first method above:—*i.e.*, one of its cords being taken as the circle, the other two were inverses of one another with regard to it. But, as soon as he mentioned to me that the polyhedron, corresponding to a composite knot consisting of two separate once-beknotted 5-folds on the same string, satisfies the special conditions of the present question (though inadmissible on other grounds), I saw why I had failed in obtaining unifilars by the first of the two methods above. For the purpose of avoiding trifilars from the first I had always made the curve traced by either end of the moving diameter (in the process of § 9 above) *cross* the great circle wherever it met it, so as to join that traced by the other end. No insertions of new meshes could then reduce the whole to a unifilar without depriving it of the property for which it was sought.

11. But if we make the closed curve traced by one end of the moving diameter *touch* the great circle in one point, the point of contact must of course be regarded as a *crossing*, while the circle and the closed curve necessarily fuse into one continuous line. The same happens with the curve traced by the opposite end of the diameter. Thus we may obtain with the greatest ease any number of unifilars satisfying the conditions. And it is clear that, by a slight extension of the definition above, all such knots will be brought under the general term amphicheiral. To make them true knots, *i.e.*, not composites, the

curves traced by the ends of the diameter must intersect one another, which implies that they must each cut the great circle in two points at least besides touching it at one or more. Hence the lowest knottiness in which they can possibly occur is 10-fold; *i.e.*, 2 points of contact with the great circle, 4 intersections with it, and 4 intersections of the two branches.

This process fails when applied in connection with the second method of § 9, for it brings in triple points which cannot be opened up into three double ones without depriving the whole figure of the desired property.

12. The 10-fold, whose genesis is described in last section, has the form shown in Plate LXXIX. fig. D, where the great circle is made prominent. It is easily recognised as the ordinary amphicheiral, fig. 31, of Plate LXXX. The reason why it figures in both categories is that the arrangement of the right or left handed meshes, being symmetrical, is not changed by reversion. Thus every ordinary amphicheiral, which is in this sense symmetrical, belongs also to the new kind of amphicheirals with which we are now dealing.

Plate LXXIX. fig. A shows a 12-fold knot, which is its own inverse with regard to the part drawn as nearly circular, and which is not amphicheiral in the ordinary sense.

Equal distortions of two corresponding parts give it the new form fig. B, which is also its own inverse with regard to the circular part.

But if, as in fig. C, we perform one of these distortions alone, the form is no longer its own inverse. But it is certainly amphicheiral, in the sense that it can be distorted into its own perversion. This is effected, of course, by undoing the single distortion which produced C from A, and inflicting the other of the pair of distortions which, together, produced B from A.

13. Thus there are at least four different senses in which a knot may be amphicheiral.

A(α) Those in which the systems of right and left hand meshes are similar and congruent.

A(β) Unsymmetrical distortions of any of the preceding, when such exist. [When the distortion is symmetrical the knot remains one of A(α).]

B(α) Those in which the systems of right and left hand meshes are similar but not congruent.

B(β) Unsymmetrical distortions of any of the preceding. [When the distortion is symmetrical the knot remains one of B(α).]

A and B may be spoken of as different *Orders*, the *First* and *Second*; α and β as *Classes*, *First* and *Second*. As already stated, the knot of fig. D belongs to both orders. But no knot can belong either to both classes of one order, or to the first of one order and the second of the other.

14. In fig. (D) the 10-fold (fig. 31) of § 11 is drawn so as to exhibit its symmetry. And we thus see at a glance that there are at least two ways

(indicated by *heavier* lines, one continuous, the other dotted) in which we can choose the laps which are to form the circle with regard to which it is its own inverse.

Fig. 38 of the 10-folds, which by reason of its symmetry belongs to both orders of amphicheirals, can have its circles shown as in figs. (E) and (F).

15. But if we take a non-symmetrical knot of the kind B(α), such as fig. A above treated, we obtain some still more striking results as to the number of ways in which we can choose the laps which form the circular portion. In this figure corresponding right and left handed meshes are marked with the same letter.

Thus, if we throw out the right hand mesh, *d*, from the contents of the circle and take in the left hand *d* instead, the figure (drawn to show the new circle) becomes fig. G.

If we throw out *f*, and take the amplexum instead, we obtain fig. H.

But, if we throw out from the circle *g*, *c*, and *e*, and take instead of them the corresponding external meshes, the figure takes the curious form K. Here the full line is the new boundary between the two halves of the figure. This new boundary, as well as the entire figure, is easily seen to be its own inverse with regard to the part bounded by the heavier portion of the full line. This, however, is only one of four ways in which it might be selected from the full line alone. Such modifications are very curious as well as numerous, but we cannot pursue them here.

16. In the upper rows of Plate LXXIX. I have given the amphicheirals of the first class, up to the tenfolds inclusive. They are drawn on the principle of § 4 above, and the first form in which each presented itself has been preserved. A comparison of these, with the corresponding figures as drawn in Plate LXXX. directly from KIRKMAN'S results, is very instructive.

[*Added*, Oct. 19, 1885.—Though the general statement in § 11 above is true from the point of view there taken, there is a possibility of evading it. Thus, if we draw a figure like E, Plate LXXIX., but with a four-pointed star inside, we get vii. of the 8-folds; which is thus shown to be an amphicheiral of the Second, as well as of the First, Order. But, if we try a three-pointed star, we get the simplest trifilar locking; as in Part I. § 42 (1), and Part II. § 8.]

II. *Census of Tenfold Knottiness.*

17. Omitting composites, the number of separate types of 10 fold knottiness is, as shown in Plates LXXX., LXXXI., 123. Of these 48 are unique, while the remaining 74 give 315 distinct forms, 364 individuals in all. The largest number of distinct forms for one type is 12; and there are two such groups. One type which furnishes a group of 10, has 4 of them amphicheirals of the first order and first class, the remainder of the second class.

Each of the figures is drawn in the special deformation in which it is presented by the polyhedral method; and, for reference, the corresponding designation of the knot in KIRKMAN'S list is appended to it.

18. Of the 107 partitions of 20, under the limits imposed by the nature of a knot, 52 only are utilised; the rest belonging to links, composites, &c. These are as below; each being followed by a distinctive letter, which will presently be employed (for brevity) in place of it.

For knots with 6 right-handed and 6 left-handed meshes:—

653222 A	544322 F
643322 B	543332 G
633332 C	533333 H
554222 D	444332 K
553322 E	443333 L

For 5 meshes of one class and 7 of the other:—

77222 *a*	65432 *l*	5522222 α
76322 *b*	65333 *m*	5432222 β
75422 *c*	64442 *n*	5333222 γ
75332 *d*	64433 *p*	4442222 δ
74432 *e*	55532 *q*	4433222 ϵ
74333 *f*	55442 *r*	4333322 ζ
66422 *g*	55433 *s*	3333332 η
66332 *h*	54443 *t*	
65522 *k*	44444 *u*	

For 4 of one and 8 of the other:—

8732 a	7652 f	43322222 θ
8633 b	7643 g	33332222 κ
8552 c	7544 h	
8543 d	6653 k	
7742 e	6554 l	

And for 3 of one and 9 of the other:—

992 p	965 s	332222222 λ
983 q	875 t	
974 r	776 u	

19. In Part II. of this series I arranged the types of each degree of knottiness in the order in which their respective deformations first appeared in Mr

ERRATUM.—Page 501, par. 17, line 2, *for* 48, *read* 49.

KIRKMAN's lists. This had the disadvantage of mixing up together types with very different relative numbers of right and left handed meshes. On the present occasion I have taken in the first rank the knots which have an equal number of meshes (six) of each kind, next those which have respectively 5 and 7, 4 and 8, &c. This will considerably simplify the process of seeking for any particular ten-fold in so long a list. The arrangement of the various types in each rank, however, follows somewhat closely the order of their earliest appearance in the first list which I got from Mr KIRKMAN, that upon which I commenced the present work.

To identify any 10 fold, all that is necessary is to count the numbers of corners in the respective right and left handed meshes, look out the contracted expressions for the corresponding partitions of 20 in § 18, and then search below for the symbol, or pair of letters so obtained. Their *order*, of course, is immaterial, as it can be altered by a mere change of mode of projection. If the symbol occur more than once, a closer examination must be made, account being now taken of the way in which the right, *or* the left handed, meshes are coupled together. This is easily done as in § 20 of my first paper.

20. The number of distinct forms which I detected as not contained in Mr KIRKMAN's first list of 10 folds bears a far smaller ratio to the whole than was the case with the ninefolds. I consider that this is due not to my remissness, but to Mr KIRKMAN's improvements in his methods, *i.e.*, rather to the non-existence than to the non-detection of omissions; and I think it is improbable that any distinct variety of a recognised type has escaped detection. Thus in the present census some types may be omitted (this is more likely to be true of unique types than of others); and I may have, as already indicated, grouped in two or more smaller detachments the varieties of one and the same type. But the possibility of either defect is due to the somewhat tentative nature of the methods employed.

The guarded way in which I spoke (Part II., § 1) of the completeness of the *Census* has been justified by a recent observation made by Mr KIRKMAN, viz., a 9 fold not included either in his list or in mine. Fortunately this knot, figured as fig. L, Pl. LXXIX., is not a new type but a distinct form of type VI. of the 9 folds as shown in the Plate attached to Part II. My methods ought to have supplied this additional member of a group, of which some forms had been furnished by KIRKMAN; but I had not, at the time, much readiness in applying them. The labour of the 10 folds has made me much more skilful than before in this matter.

21. In the following list, the order is the same as in the plates. The symbols for each knot are so written that the second, in all cases, corresponds to the group of meshes to which (as the figure happens to be drawn) the amplex belongs.

The various Types of Tenfolds with their distinct Forms.

Six right and six left hand meshes; 24 non-unique types, 14 unique; 133 individual distinct forms in all. Amphicheirals of the first order and first class are marked by a bar over the symbol instead of a repetition.

1. $\bar{C}$, $\bar{G}$, GC, GG, CG, KC, KG, $\bar{G}$, GK, $\bar{K}$. 2. FC, GF, GF, GF.
3. HB, LB, BC, GB, BG, KB, HF, FC, FG, LF, GF, FK.
4. GE, KE, GE, GE, BK, GB, GB, KB, BG, GB, EK, EG.
5. FF, KB, FB, BF, FF, FK. 6. GE, LE, KE.
7. FE, FG, FB, EB, EG, EE, FE, FG, FB. 8. FK, KF. 9. $\bar{F}$, FF, $\bar{F}$. 10. GF, KF.
11. BF, KE, BB, GF, KG, GB, EF, KB, BE. 12. LF, LF, FH. 13. KG, $\bar{K}$, $\bar{G}$.
14. $\bar{B}$, $\bar{E}$, $\bar{G}$, EB, BG, EG. 15. $\bar{A}$, EA, $\bar{E}$, 16. BB, FB, KB, KF, FB, FF.
17. GF, GF. 18. FD, DB, KD. 19. FA, KA, FA, GA, GA, EA.
20. BA, KA, KA, AF. 21. GA, GA, AF, BA. 22. FB, $\bar{B}$, $\bar{F}$. 23. DB, FD.
24. EA, AA. 25. KG. 26. $\bar{G}$. 27. $\bar{F}$. 28. LK. 29. $\bar{K}$. 30. LG.
31. $\bar{F}$. 32. EF. 33. FE. 34. EF. 35. $\bar{D}$. 36. AD. 37. $\bar{A}$. 38. $\bar{H}$.

Five meshes of one kind, seven of the other. Forty-three non-unique types, twenty-one unique—200 distinct forms in all.

39. ϵs, ϵs, ϵp, γp, $s\gamma$, $s\gamma$. 40. ϵm, ϵm, ϵf. 41. ϵl, ϵe, γl, γe, ηe, ηl, ζl, ζe, $e\zeta$, $l\zeta$.
42. ζq, γl, ϵl, γq, ϵq, ζl. 43. ϵf, ϵm, ϵp, ϵs, γf, γm, γs, γp, $p\zeta$, $s\zeta$, ζm, ζf. 44. $s\epsilon$, $t\epsilon$.
45. ζd, ζh, ϵh, ϵh, ϵd, ϵd, $h\zeta$, $d\zeta$. 46. ζl, ζl, ηl. 47. $k\gamma$, ϵk, ηk, ζk.
48. ϵh, ϵd, ϵm, $h\beta$, $m\beta$, $d\beta$. 49. ζc, ζc, ηc, γc, ζc, ϵc. 50. $g\gamma$, ϵg, ζg, ζg.
51. ζb, ζb, ζb, $b\epsilon$, γb. 52. βb, ϵb, $h\beta$, ϵh, ϵh, ϵb. 53. ϵr, βr, ϵl, ϵl, βl, $l\beta$. 54. $p\epsilon$, $t\epsilon$.
55. $s\beta$, $t\beta$, $m\beta$, $s\beta$, $p\beta$, $s\beta$. 56. δf, δp, δs. 57. $n\gamma$, γn, ϵn, ϵn.
58. ζr, $r\gamma$, ϵe, γe, ζe, ϵr. 59. δl, δq. 60. ϵe, $e\gamma$, $l\gamma$, ϵl, ζl, ζe.
61. ϵe, ϵl, ϵt, $t\beta$, $e\beta$, $l\beta$. 62. $e\beta$, $p\beta$, $l\beta$, ϵl, ϵp, ϵe. 63. ϵk, $k\gamma$, ζk. 64. βl, βq, $s\beta$.
65. $r\beta$, ϵc, ϵr, βc. 66. ϵb, βb, ϵb. 67. $d\beta$, $m\beta$, βl. 68. $d\beta$, βl, $s\beta$.
69. ϵg, $g\gamma$. 70. δd, $l\delta$. 71. βr, $t\beta$, $e\beta$. 72. $l\beta$, $r\beta$. 73. pa, ta, la, ra.
74. ϵc, $r\beta$, $r\epsilon$, $c\beta$. 75. ϵk, βk. 76. βc, ϵc. 77. ϵa, ϵa, $a\beta$. 78. $b\beta$, $h\beta$.
79. βc, ϵc. 80. ra, ac. 81. ha, ab. 82. ζu. 83. $s\epsilon$. 84. ϵt. 85. ζt.
86. ζr. 87. ηs. 88. $p\zeta$. 89. ϵr. 90. ζn. 91. ϵq. 92. $r\epsilon$. 93. ζs.
94. $m\zeta$. 95. $r\epsilon$. 96. ϵl. 97. $l\epsilon$. 98. ϵl. 99. ϵh, 100. βk. 101. $b\beta$. 102. $a a$.

Four meshes of one kind, eight of the other. Seven non-unique types and eight unique—twenty-five distinct forms in all.

103. κf, θf. 104. κa, κa, θa. 105. κd, κg, dθ, gθ. 106. κc, θc. 107. θd, lθ.
108. θb, gθ. 109. θl, θh. 110. κk. 111. lκ. 112. κh. 113. κg.
114. θk. 115. θf. 116. θe. 117. aθ.

Three meshes of one kind, nine of the other. Six unique types.

118. λu. 119. λq. 120. λp. 121. λs. 122. λr. 123. λt.

22. The nature of the special difficulty hinted at in the beginning of the paper will be easily seen from the simple case illustrated by the four figures M, Plate LXXIX. They denote various forms of the type 40 of Plate LXXX.

It will be noticed that the crossings A, B, C may, one, two, or all, be changed from one lap of the string to the other, as shown in the second figure. Also D may be transferred to a position between A and B, or between A and C. There are thus two positions for each of A, B, and C; and three positions for D; giving 24 combinations in all. But it is clear that we need not shift D at all, so far as the outline of the figure is concerned; for a mere rotation of the whole in its own plane (as A, B, and C are similar to one another) will effect this. Then a change of B will merely give the *reverse* of the figure obtained by changing C. Again, by inverting the first figure about a point in the inner mesh, we get the second. If we had changed C, and then inverted, we should have got the same figure as by changing simultaneously A and B. By changing C alone in the first, we get the third; but by shifting D in the first we get the fourth; and these two are obviously each the reverse of the other. Thus the 24 figures reduce to the three shown in Plate LXXX. As another example, take the third form of the third type of 10 folds as given in Plate LXXX. Two of thecrossings on its external boundary can be shifted, but each to one other place only. The form itself, and the same with one or both of these crossings shifted, give a set of four; each of which can take five new forms by the shifting of other crossings. But it will be found that the 24 forms thus obtained are identical in pairs;—thus reducing to the 12 given in the Plate.

23. Mr KIRKMAN informs me that he has nearly completed the enumeration and description of the polyhedra corresponding to the unifilar 11 folds. I hope, therefore, at some future time to lay before the Society the census of 11 fold knottiness. This was the limit to which I ventured to aspire nearly two years ago, in a paper* which, I am happy to think, directed Mr KIRKMAN'S attention to the subject.

24. It must be remembered that, so far as these instalments of the census have gone, we have proceeded on the supposition that in each form the crossings have been taken *over and under alternately*. But, as was shown in § 13 of Part I., as soon as we come to 8 folds we have some knots which may preserve their knottiness even when this condition is not fulfilled. These ought, therefore, to be regarded as proper knots and to be included in the census as new and distinct types. This is a difficulty of a very formidable order. It depends upon the property which I have called *Knotfulness* (Part I. § 35; II. § 6), for whose treatment I have not yet managed to devise any but tentative methods.

To show, by a single case (even though not thoroughly worked out) of how

* *Listing's Topologie*, § 22, *Phil. Mag.*, *Jan.* 1884.

great importance is this consideration, I have appended to Plate LXXIX. the five figures N ; with the nature of each crossing indicated. The numbers affixed show the positions they occupied in the census of 8 folds, when the crossings were alternately over and under. *Then* they were all unique knots, incapable of any change of form. *Now* they are capable of being changed into one another. The linked trefoils in N, xiv. are perversions of one another. But we may have them of the same kind, and the link such that there shall be continuations of sign. This was briefly treated in Part I. § 42, 1. How many new types may by this process be added to the census, I have not yet made out with certainty even for the 8 folds.

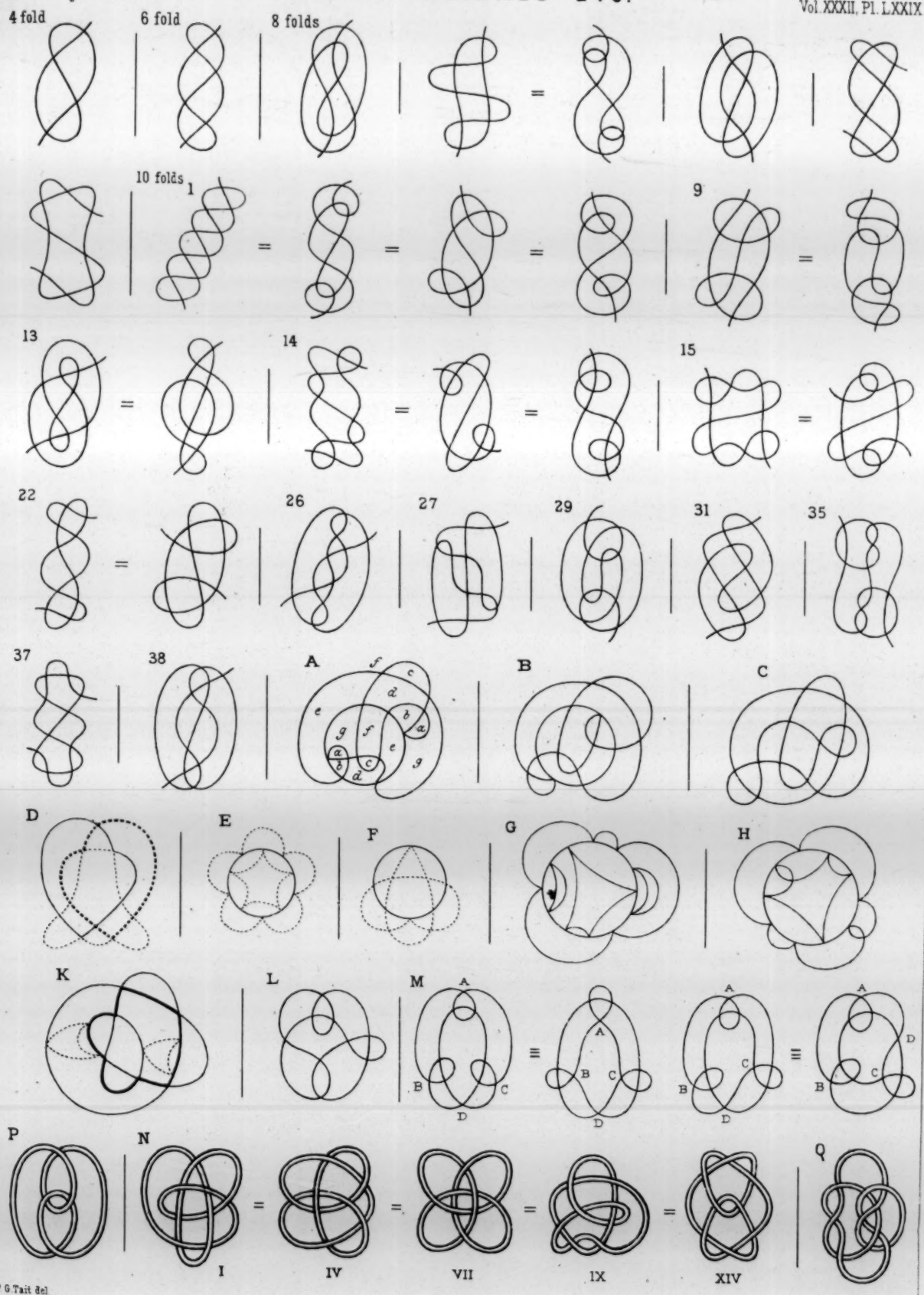
P.S.—I may introduce here, as a note on Part I. of this series of papers, a remark or two with reference to the three-ply plaits treated there ; in § 27 as fully knotted, and in § 42, 1 as fully beknotted. First, it is obvious that the 4 fold, as first drawn in § 17, should have been repeated in Plate XV., at the head of the series of figures 15, 16, 17, &c. It is the case of $3n+1$ of § 27, with $n=1$. Secondly, with its crossings arranged as in fig. P, Plate LXXIX. of the present paper, it should have come in before figs. 24 and 25 of Plate XVI Part I., in a form reducible to the ordinary trefoil. Fig. 25 of that Plate puzzled me much at the time when I drew it, for I could not account for the production of a 3 fold and a 5 fold (linked) from a figure possessing a peculiar kind of (cyclonic ?) symmetry round an axis. The figure is *accurate*, but I now see that it gives an erroneous impression of the true nature of the knotfulness. The correct idea is at once obtained from Plate LXXIX., fig. Q, of the present paper. The knot is an irreducible trefoil, with a second of the same character tied *twice* through one of its three-cornered meshes.

(*Added, September* 3, 1885.)

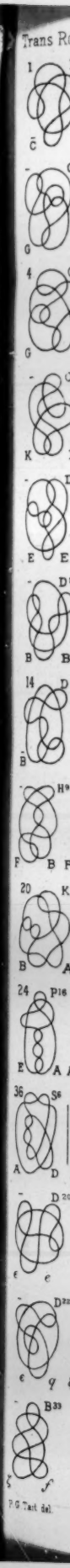
Three days ago I received from Mr Lockyer a copy of a most interesting pamphlet "*On Knots, with a Census for Order Ten*," a reprint from the *Trans Connecticut Acad.*, vol. vii., 1885. The author, Prof. Little of the State University, Nebraska, has made an independent census of 10 fold knots ; employing the partition method, with some new special rules analogous to those in Mr Kirkman's recent paper. So far as I can judge from a first hasty comparison of the mere number of types and forms in each class, there are important discrepancies between this census and my own. One of these, at least, is due to a slip on my part ; and, as my paper was not printed off when I detected it, I have taken the opportunity of correcting it both in the text and in the corresponding Plate. I had failed to notice that the two forms which now appear under No. 109 really belong to one type. Hence I have had to

reduce by one the number of the distinct 10 fold types which was originally given in my paper. I hope in time to make a full comparison of the two versions of the census. Meanwhile I may note that there is one omission, and also one duplicate, in Class VI. of Mr LITTLE's version. This duplicate has led him to insert one type too many.

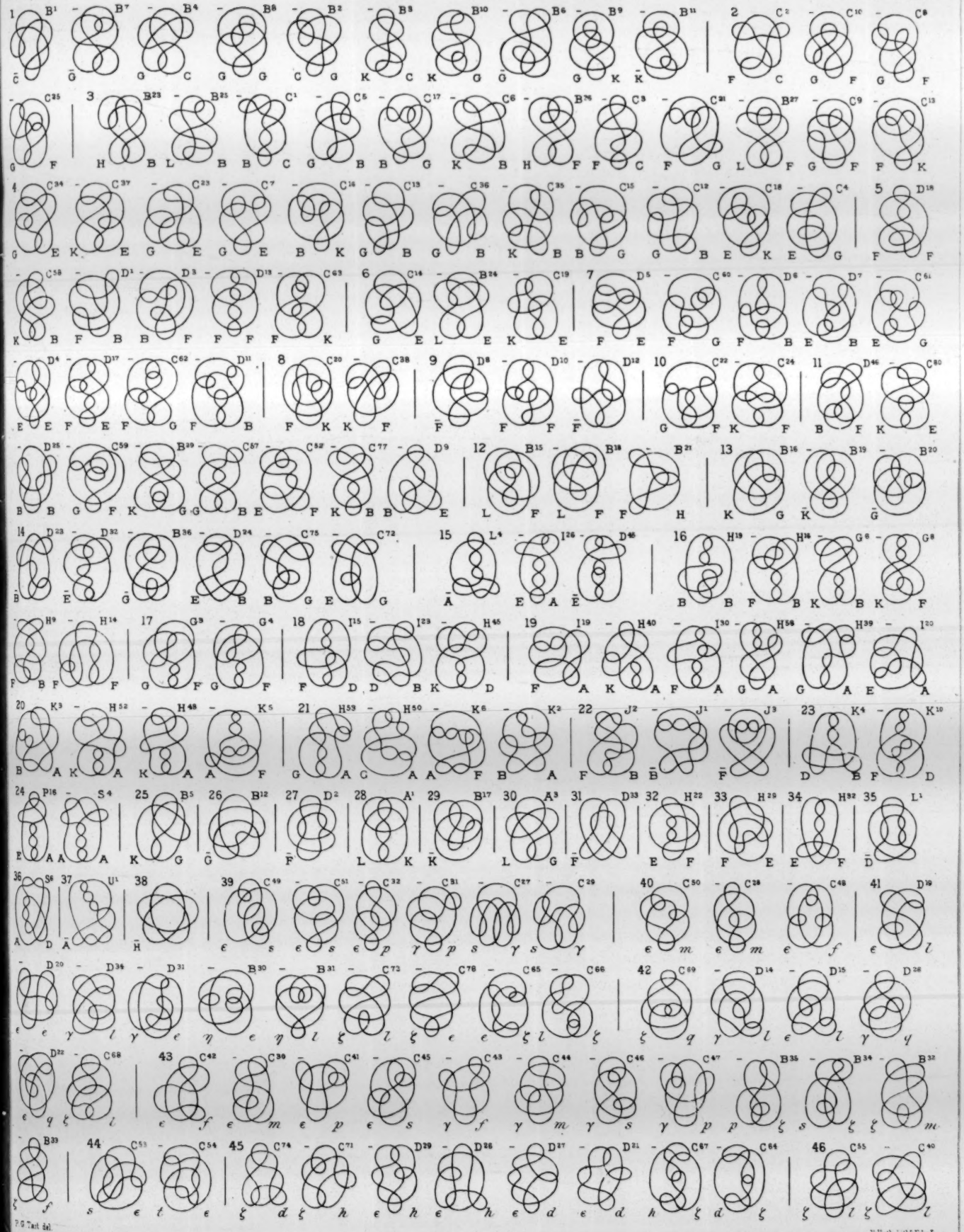
More than a month ago I received from Mr KIRKMAN the full polyhedral data for the census of 11 folds, which I hope soon to undertake. The number of forms is so great, and the time I can spare for the work so limited, that I cannot promise it at an early date.


4 fold
6 fold
8 folds
10 folds
1
9
13
14
15
22
26
27
29
31
35
37
38
A
B
C
D
E
F
G
H
K
L
M
N
P
Q
I
IV
VII
IX
XIV

BRITISH
4 JU 87
MUSEUM



TENFOLD KNOTTINESS.



TENFOLD KNOTTINESS.



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XXVIII.—*A New Graphic Analysis of the Kinematics of Mechanisms.*

By Professor Robert H. Smith, Mason College, Birmingham. (Plate LXXXII.)

(Read 19th January 1885.)

A mechanism may be defined as a combination of plates, bars, or flexible members jointed together, so that, while the parts may move relatively to each other, the relative positions of all the different parts are determinate for each given possible relative position of any two parts.

It follows immediately that the simultaneous relative displacements, velocities, and accelerations of velocity of all parts are also strictly determinate.

This determination, by accurate graphic means, forms the subject of this paper. In it those mechanisms alone are considered that are composed of *rigid* members, the motions of whose parts are all continually parallel to *one* plane, the constancy of the plane being defined relatively to one of the members of the mechanism itself.

The different rigid members of mechanisms will be termed "bars." That bar relatively to which the displacements, velocities, and velocity-accelerations are measured, will be termed the *base-plate* or *bed-plate*. The displacement, velocity, and velocity-acceleration of the base-plate remain, of course, always zero.

To avoid repetition of the cumbersome phrase "relatively to," this phrase is discarded for the shorter expressions "through," "past," "over," or "round." Every possible motion or other vector is through some field in which positions and directions may be defined in a determinate manner. It is improper to speak of the motion of one point past another, without mention of the particular field through which the motion is measured, because two points alone are inadequate to define a field in which vectors may be measured. In what follows, when the field of reference is not mentioned, it is to be understood that the vectors are taken through the "field of the base-plate," *i.e.*, through the space surrounding and defined with reference to the base-plate. On the other hand, it is perfectly definite to speak of the motion of a point or of a bar over, past, or round another bar, the motion being understood, without further mention, to be measured through the field of the bar round which it takes place.

The graphic determination of the simultaneous positions of the various bars of most commonly used mechanisms is easy and well understood. When difficulties occur, as in various engine reversing link-motions, the special methods here explained enable them to be readily overcome. The *loci* of the successive positions of the various parts may be called the "motion curves" or

more simply the "paths" of these parts. These paths are drawn in on the "mechanism diagram."

From these "paths" the *displacements* from any assumed initial configuration can be directly measured. It may, however, be often advantageous to have a separate "displacement diagram," consisting of a series of curves, showing the successive simultaneous displacements of all important points of the mechanism as vector-radii from one and the same pole. These curves in the "displacement diagram" are, of course, exact copies of the "paths" in the "mechanism diagram."

Let ABC and BDE be two bars linked together at the joint B. Let P′ be the pole of the displacement diagram, and let the curves A′A′, B′B′, D′D′ be the displacement curves of the three points ABD. All these curves, of course, pass through the pole P′. $P'A_1'$, $P'B_1'$, and $P'D_1'$, being simultaneous displacements of AB and D, draw on $A_1'B_1'$ and $B_1'D_1'$ as bases, the triangles $A_1'B_1'C_1'$ and $B_1'D_1'E_1'$ similar to the triangles ABC and BDE in the mechanism. It can easily be shown that $P'C_1'$ and $P'E_1'$ are the simultaneous displacements of C and E. By joining all the points C′ and E′ found by such constructions, the displacement curves of C and E can be drawn in. Numerous simultaneous points on the various displacement curves should be marked, and numbered 1, 2, 3, 4, &c.

The advantage of such a displacement diagram over the set of "paths" dispersed over the mechanism diagram, consists in the greater facility of comparison between the displacements of the various parts of the mechanism that it affords. Thus, comparing simultaneous points A′ and C′ belonging to the same bar, the vector A′C′ is the displacement of C′ past (or relatively to) A in the base-plate field. The same holds for points in different bars; thus, D′C′ is the displacement of C past D in the base-plate field. As a useful fact of assistance in drawing these diagrams, it may be noted that any line, such as A′C′ belonging to *one* bar, is perpendicular to the line bisecting the angle between the simultaneous and "initial" positions of the line AC in the mechanism. This does not, however, apply to a line, such as E′C′, joining points belonging to *different* bars.

The method of obtaining the velocities by taking the small differences of the displacements, which method is the basis of kinematic analysis developed by means of the differential calculus, has often been adopted as a graphic process for the solution of specially complicated problems. After constructing the velocity hodographs, the same method may be followed to find the velocity accelerations. As a graphic process, however, this method is capable of no accuracy; it is, in fact, practically useless.

Professor REULEAUX'S method of centroids, more properly called axoids, has now become famous; but, although the writer has constructed the axoids of

many mechanisms, he has so far failed to discover any practical use to which these axoids can be applied. They are very tedious of construction, and when constructed furnish no direct means of measurement of any useful quantities.

The method now proposed furnishes velocity and acceleration diagrams, somewhat similar in appearance to stress diagrams, which show the true directions and magnitudes to scale of the velocities and velocity accelerations of all points in the mechanism; there being one pole only for each diagram from which all vectors radiate, so that the velocities or accelerations of all parts and at all times of the complete cyclic period can be compared with maximum facility.

Fig. 1.—Let ABCD be a rigid bar. Suppose the velocity of A over the base-plate P to be known. Choose any pole p, and draw pa parallel to the velocity of A, and of a length to represent its magnitude to any scale considered convenient for the velocity diagram. If now the angular velocity ω of the bar be also known, ab may be plotted perpendicular to AB, and equal in length to $\omega \cdot \overline{AB}$ to the above velocity scale. Then, pb is the velocity of B over the base-plate. If, instead of ω being known, we know the velocity of B as well as that of A, then pb may be plotted directly, and joining ab the angular velocity may, if desired, be calculated by dividing ab by AB. Since the (relative) velocity of C round A is perpendicular to AC, and its relative velocity round B is perpendicular to BC; if ac and bc are drawn perpendicular to AC and BC, their intersection c gives pc the velocity of C through the base-plate field. Similarly, pd is found to measure the velocity of D. The diagram gives not only the velocities over the base-plate P, but also all the velocities of pairs of points relative to each other. For instance, bd is that of D round B, and db is that of B round D, these relative velocities being through the field of the base-plate P.

It is clear that the figure $abcd$ forms a diagram of the bar ABCD to a diminished scale and turned through a right angle in the direction of ω.* Further, on this new diagram of the bar, altered in scale and rotated through 90°, the pole p represents the position of the instantaneous axis of rotation. Theoretically, the original diagram ABCD, with the position P of the instantaneous axis added, would serve equally well as a diagram of velocities, the scale being chosen suitably, so that PA would represent the velocity of A. But for practical graphic construction it cannot be so used, for several reasons. Firstly, the usual variation of the position of the instantaneous axis is extremely inconvenient, and in almost all mechanisms this axis periodically recedes to an infinite distance. Secondly, the scale to which it could represent the velocities

* In an abstract of this paper written for the engineering journals, the late Professor FLEEMING JENKIN very expressively called $abcd$ the "image" of ABCD. In the acceleration diagram another "image" $a'b'c'd'$ appears.

is always varying throughout the periodic motion of the mechanism; it is always *necessarily* an awkward scale to measure to, and it periodically becomes in most cases an impossible scale by becoming infinitely large. Thirdly, the various bars of a mechanism have all different instantaneous axes, and the scales of the velocities would be entirely different for the different bars. As will be shown presently, in the method explained in this paper, the velocity diagrams of all the bars of even the most complicated mechanisms are all grouped together so as all to radiate from one pole, and so as to be to the same scale for all the bars and at all times throughout the periodic motion of the mechanism.

A similar construction is applicable to accelerations of velocity. In fig. 2 let ABCD be one rigid bar. Let the acceleration of velocity of point A through the field of the base-plate be known, and represented in direction and magnitude by $p'a'$ drawn from any convenient pole p' to any convenient acceleration scale. The acceleration of B can be obtained by adding to the vector $p'a'$ the vector acceleration of B in its relative motion round A. If ω be the angular velocity of the bar in the base-plate field, and if ω' be the acceleration of angular velocity, the radial or centripetal component of velocity acceleration is $\omega^2 \cdot \overline{AB}$ and the tangential component is $\omega' \cdot \overline{AB}$. The whole acceleration of relative velocity is therefore, $\overline{AB} \cdot \sqrt{\omega^4 + \omega'^2}$, and its direction is inclined to BA by the angle $\tan^{-1} \frac{\omega}{\omega^2}$. This angle is the same for every pair of points in the same rigid bar; and, since the magnitude of the acceleration of one point round any other is proportionate to the distance between them, therefore, if $a'b'$ be drawn inclined to BA at the angle $\tan^{-1} \frac{\omega'}{\omega^2}$ and of length $AB\sqrt{\omega^4 + \omega'^2}$, and if the figure $a'b'c'd'$ be made similar to that of the bar ABCD, then $p'b'$, $p'c'$, $p'd'$, will be the accelerations of the points BCD in the base-plate field. Further $a'c'$, for instance, is the acceleration of C round A. In the graphic construction it is simplest to plot $a'\beta' = \overline{AB} \cdot \omega^2$, and parallel to BA (not AB), and $\beta'b' = \overline{AB} \cdot \omega'$ perpendicular to AB and in the direction given by the sign of ω'. The radial component is usually obtainable from the already constructed velocity diagram, where the velocity of B round A is called ab, and the radial acceleration is therefore $\frac{(ab)^2}{AB}$. Fig. 3 gives the two most ready graphic constructions for calculating $\frac{(ab)^2}{AB}$. In figs. (1) and (2) the velocity ab is plotted along BA from B to β towards A in (1); and away from A in (2). From B as centre with Bβ as radius, a circular arc is struck intersecting in β_1 any other radius from A. From β is drawn $\beta\beta'$ parallel to that other radius, and intersecting Bβ_1 in β'. Then Bβ' is the radial acceleration $\frac{(ab)^2}{AB}$. In (3) (ab) is plotted from B as Bβ perpendicular to AB, and a circular arc with centre in

BA is struck through A and β. This arc cuts the diameter AB in β' giving Bβ' the desired radial acceleration.

If the bar be plotted to the scale $m''=1''$, m being a fraction; and if the velocity be plotted to the scale $n''=1$ inch/second; then such constructions give the acceleration to the scale $\left(\frac{n^2}{m}\right)$ inch $=1$ inch/second.[2]

It is evident that the figure $a'b'c'd'$ of the acceleration diagram is simply a reproduction of the figure ABCD of the bar altered in scale and rotated through an angle $\left\{180^\circ - \tan^{-1}\frac{\omega'}{\omega^2}\right\}$ in the direction of ω where in $\tan^{-1}\frac{\omega'}{\omega^2}$ the sign of ω' is to be taken positive or negative according as it is in the same or the opposite direction to that of ω. In this altered diagram p' is the point of the bar if the bar extends so far, or of its field if it does not extend so far, which suffers no acceleration or is moving uniformly in a straight line. This point does not in general coincide with the instantaneous axis of rotation. If the velocity diagram were rotated and altered in scale, and placed on top of the acceleration diagram so that $a'b'c'd'$ coincided with $abcd$, then $p'p$ would represent in direction and magnitude the acceleration of that line in the bar or in the field of the bar which is at any time the instantaneous axis.*

If G be the centre of inertia of the bar and the similar points g and g' be plotted in the velocity and acceleration diagrams, then the products of the bar-mass by pg and $p'g'$ are respectively the integral momentum and the integral acceleration of momentum of the whole bar.

In what follows the capital P will denote the base-plate through whose field the velocities, &c., are reckoned.

The pole of the velocity diagram will be called p. The pole of the acceleration diagram will be called p'.

Points in the mechanism will be named by capital letters ABC, &c.

The corresponding points in the velocity diagram will be named by the same letters in small type, abc, &c.; so that pc will denote the velocity of C over the base-plate and bc the velocity of C round B, and cb that of B round C.

The corresponding points in the acceleration diagram will be named by accented small letters; this being in accordance with the common mathematical convention, whereby x' represents $\frac{dx}{dt}$

In finding, for instance, the point b, it is sometimes necessary to find other points which are not afterwards required in the completed diagram. When such construction points require to be named, they will be called β_1, β_2, &c.,

* The acceleration "image" of a bar moving without rotation reduces to a point. The velocity "image" of a bar moving without rotation reduces to a point.

if used to find b in the velocity diagram, and β_1' β_2', &c., if used to find b' in the acceleration diagram.

In the displacement diagrams described above, the accented capitals A′B′C′ &c., are suitable.

The simplest mechanism is that with four bars and with two joints, P_1P_2 in the base-plate, and two joints AB coupling the other three bars together. An example is shown in fig. 4, the calculations being made for five different phases of the periodic motion.

The velocity of the crank-pin A is supposed known at each phase. From any pole p, and to any convenient scale this velocity pa is plotted perpendicularly to P_1A. From p a line is drawn perpendicularly to P_2B. Evidently the extremity b of bp, the velocity of B, must lie in this line. But also pb pa plus a velocity perpendicular to AB. Therefore from a a line is drawn perpendicular to AB to meet the above line in b. Thus pb is determined. In the example pa is taken of the same magnitude at all the five phases.

To obtain the acceleration diagram we assume the acceleration of A. This is constant in magnitude $=\frac{(pa)^2}{P_1A}$, on the supposition that pa is also constant in magnitude and is wholly radial, since pa is taken as constant.

From any pole p' this acceleration $\frac{(pa)^2}{P_1A}=p'a'$ is plotted parallel to AP_1 (not to P_1A).

The calculation of the magnitude is performed by the graphic construction previously explained. By the same construction the magnitudes $\frac{(pb)^2}{P_2B}$ and $\frac{(ab)^2}{AB}$ of the radial components of the accelerations of B round P_2 and round A are found and plotted off from p' (as $p'\beta'$) and from a' ($a'\beta'$) parallel to BP_2 and to BA. From these two points β' thus obtained, lines are drawn perpendicular to BP_2 and to BA. The point b' sought for must lie on both of these last lines, and is, therefore, at their intersection. The acceleration $p'b'$ of the joint B through the field of P is thus obtained for the five different phases of the motion. The method of procedure is plain. Each joint of the mechanism is a point in two different bars, and therefore the calculation for that joint may be approached, as it were, from two different sides. In each of the two calculations there is one element missing, and the last stage of the calculation cannot be completed directly; for example, approaching the calculation of the acceleration of B through A, we can calculate the radial component (parallel to BA) of the acceleration that has to be added to that of A, but of the tangential component the direction only is known, but this gives a line in which the desired point must lie. Another conditioning line being similarly found by approaching the calculation in another way, the point is found at the intersection of these two lines.

In the ordinary steam-engine with guide bars, the radius bar BP_2 swinging in the base-plate-bearing at P_2 is replaced by the cross-head sliding in straight guides which form part of the base-plate. The effect is the same as if BP_2 were infinitely long. On account of the cross-head joint being guided in a straight line, passing through the crank journal centre, a symmetry is given to the motion which materially lightens the labour of drawing complete velocity and acceleration diagrams. Fig. 5 illustrates this.

Here the four positions 1, 2, 3, and 4 of the crankpin A are taken equidistant from the dead-points O and O′. Therefore the two cross-head positions B_1 and B_4 coincide, as do also B_2 and B_3. Therefore also the four velocities pa_1, pa_2, pa_3, and pa_4 are equally inclined to the velocity line pb, and the four points a_1, a_2, a_3, a_4 are equidistant from the line pb. Also at 1 and 2 the connecting rod has the same inclination to the centre line, which inclination is equal and opposite to that at 3 and 4. Thus the lines a_4b_4 and a_1b_1, and a_2b_2 and a_3b_3, are equally inclined to pb; and, therefore, the velocities pb_4 and pb_1 have equal magnitudes, as also have pb_3 and pb_2. Therefore also the radial accelerations $a_1'\beta_1'$, $a_2'\beta_2'$, $a_3'\beta_3'$, $a_4'\beta_4'$ have equal magnitudes, and are equally inclined to $p'b'$; while also the tangential accelerations, $\beta_1'b_1'$, &c., are equally inclined to the same line, and are of the same length, because a_1', a_2', a_3', and a_4' are equidistant from $p'b'$. Therefore, finally, b_1' coincides with b_4', and b_2' with b_3'. The four accelerations $a'b'$ have equal magnitudes, but $p'b_2'=p'b_3'$ differs in magnitude as well as direction from $p'b_4'=p'b_1'$.

This symmetry is, of course, destroyed by want of uniformity in the rotation of the crank.

The joint lines of the bars of a mechanism, the velocity lines, and the acceleration lines need be drawn in full for one position only. The results for the other positions are indicated by numbered points on the three set of curves, which are the *loci* of the corresponding points or extremities of lines. The first set of curves are the paths of motion of the joints. The second series of curves are the hodographs of the velocities of these same joints. The third series are the *loci* of the extremities of the lines representing the velocity accelerations.

Six-bar motion is nearly equally easy to deal with by this method.

The first example given in fig. 6 is quite simple, because the velocity pa of the joint A is assumed as known, the bar P_1A being one of the quadrilateral P_1ABP_2. The determination of the velocity pb is, therefore, the same as that given already. Thus, pb and ab are drawn perpendicular to P_2B and AB, and their intersection gives b. Then the triangle abc is made similar to ABC. pd is then drawn perpendicular to P_3D, and cd to CD, the intersection giving pd the velocity of D. To find the velocity of E, there are drawn pe and de perpendicular to P_3E and DE. The construction of the acceleration diagram here offers no special difficulty.

The solution of the next example in fig. 7 is not quite so direct, because here the velocity assumed as known, namely, pa that of A, is that of a joint in the *pentagon* P_1ABCP_2. First, pa is drawn of the known magnitude and perpendicular to P_1A; and then $a\beta$ of indefinite length perpendicular to AB. Then, $p\delta$ and pc are drawn of indefinite length perpendicular to P_3D and P_2C, that is, in the directions of the velocities of D and C. The points b and d now sought for are known to lie on the lines $a\beta$ and $p\delta$, and also it is known that the line joining b and d is perpendicular to BD. Any point β on $a\beta$ is chosen, and from it $\beta\delta$ drawn perpendicular to BD; and then the triangle $\beta\delta\gamma$ is constructed similar to BDC, corresponding sides being perpendicular. The triangle bdc that is sought for must evidently be similarly placed to $\beta\delta\gamma$ between the the lines $p\delta$ and $a\beta$. Therefore, γ is joined with the intersection of $p\delta$ and $a\beta$, and this line is produced to intersect pc, drawn from p perpendicular to P_2C. This gives the true position of c, and the triangle dcb is then completed by drawing cd and cb perpendicular to CD and CB to meet $p\delta$ and $a\beta$. The point e is obtained by drawing pe and de perpendicular to P_3E and DE.

The acceleration diagram has, in this case, to be constructed according to a similar indirect method. The acceleration of A being supposed known can be plotted at once. Then the radial components of the accelerations of B round A, of C round P_2, and of D round P_3, are calculated and plotted off in their proper directions from a' and p'; their magnitudes being $\frac{(ba)^2}{BA}$, $\frac{(pc)^2}{P_2C}$, $\frac{(pd)^2}{P_3D}$. From the three points so obtained, three lines, which we may call β, γ, and δ, are drawn of indefinite length perpendicular to BA, P_2C, and P_3D. The tangential components of the above three accelerations lie along these lines, which, therefore, contain the three points b', c', and d' sought for. On the line δ, any two points, δ_1 and δ_2, are chosen, and from each the centripetal acceleration $\frac{(cd)^2}{CD}$ of C round D is plotted parallel to CD; and from the two points thus obtained are drawn two lines perpendicular to CD, to meet the line γ in two points, say γ_1 and γ_2. On the two bases, $\delta_1\gamma_1$ and $\delta_2\gamma_2$, are constructed two triangles similar to DCB, whose two vertices may be called β_1 and β_2. Neither of these points, β_1, β_2, will be found to lie on the line β, and their distances from this line may be taken as measures of the errors involved in the two guesses, δ_1, δ_2, at the position of d. The error thus found in the resulting position of β, is a linear function of the error in the guessed position of δ; and, therefore, the interpolation between these two errors in order to reduce them to zero is to be performed by simple proportion. This linear interpolation is at once effected graphically by drawing a line through β_1 and β_2, and producing it until it meets the line β. The intersection thus found will be the true position of b^1. Or, otherwise, the two error-distances of β_1 and β_2 from the line β may be plotted off from the points δ_1 and δ_2 perpendicularly to the line δ (or both in

any one direction inclined to δ), and through the two points thus obtained a straight line is drawn to cut the line δ in the true position of d'. From d' or b' thus determined, the other points are constructed as usual.

This indirect method of "two trials and two errors," and linear interpolation between them, is adopted in drawing the velocity and acceleration diagrams for the ordinary steam-engine reversing link motion. These diagrams could not be obtained except by this method. It may be mentioned that this is frequently the only practicable method by which *stress-diagrams* of immovable linkworks can be completed.

In the common steam-engine mechanism we have already had a case of one bar *sliding* on another, namely, the cross-head sliding in the guide-bars of the bed-plate. A circular slot in which sliding takes place may, of course, be looked upon as simply an incomplete pin joint of large size, the radius of the pin becoming infinite when the slot is straight. But when the radius of the slot is large, this manner of regarding the joint is not practically useful. A more direct application of the present graphic method to sliding joints is effected thus: If B be a bar sliding over the bar A, the difference of the velocities of any two touching points in B and A is a velocity parallel to the slide-surface, or "guide-surface."

Thus, the velocity of the bar A being known, the velocity of any point in B can be obtained by adding to the velocity of *any* touching point in A a velocity parallel to the guide-surface, and further adding a velocity perpendicular to the line joining this touching point with the point in B whose velocity is to be found.

This last added component is that due to the *rotation* of B in the field of the base-plate. If the touching surface of B has the same shape as that of A, so that B always "fits" on to all parts of A into contact with which it comes, and if during the sliding these fitting surfaces are forced always to lie close together, then the angular velocity of B is always the same as that of A. In this case, if the velocity of A be completely known, the linear velocity of any point in B can be calculated by adding to the velocity, which the point would have if B were rigidly attached to A, a velocity parallel to the guide-surface.

In the illustration (fig. 8), the velocity of point A round P_1 is supposed to be known, and it is plotted as pa. Then $p\beta$ and $a\beta$ are drawn perpendicular to P_1B and AB. This gives $p\beta$ the velocity that point B would have if the cross-head were rigidly attached to the guide-bars, and if βb be drawn parallel to the slot, the point b must lie in this last line. But B is guided by the radius rod P_2B. Therefore pb is drawn perpendicular to P_2B to meet βb in b; then pb is the velocity of B in the P field, and βb is the velocity of sliding in the slot.

If a block C (see fig. 9) slide in two slotted bars A and B, the first of which has a translatory velocity pa, and the second a translatory velocity pb,

evidently the method of finding the velocity pc of the block is to draw from a and b two lines parallel to the two slots in A and B. If these lines meet in c, then pc is the velocity required.

If the slotted bars have rotational instead of purely translatory velocities, then precisely the same construction is to be followed, making pa and pb the linear velocities of the touching points of the guide-surfaces in A and B. Now, however, it is evident that one and the same block cannot constantly fit close to both slotted guide-surfaces. But if two fitting blocks, one fitting the one slot and the other the other, be pinned together, then the above construction may be applied to find the velocity of the centre of the joining pin, and from the velocity of this centre it is easy to deduce by methods already explained the velocities of all other points in the two sliding blocks.

These last graphic methods have been applied to the calculation of velocity and acceleration diagrams for Player's pneumatic forging hammer, in which a combination of oscillating sleeves, through which slide levers, makes the complexity of the mechanism such as to be incapable of algebraic treatment in a manner that is at once accurate and yet not impracticably cumbersome.

The following application (see fig. 10) of the construction for sliding motion to toothed wheel gear well illustrates the complete generality of the method, and owes its interest not chiefly to its technical character.

The sketch represents four wheels, P_AA, P_BB_1, P_BB_2 and P_CC, pinned to the base-plate at P_A, P_B, and P_C. The point A of the first touches the point B_1 in the second, the two surfaces having here a common tangent to which the line $(AB_1)T_{AB}$ is drawn normal. The third wheel being mounted on the same shaft as the second, these two are to be looked upon as forming, along with the shaft, one bar of the mechanism. The third and fourth wheels touch at the common point (B_2C), and the line $(B_2C)T_{BC}$ is drawn normal to the common touching surface. The points T_{AB} and T_{BC} are in the centre lines P_AP_B and P_BP_C.

The velocity of the wheel A, and therefore of its touching point A, is supposed known, and this velocity is marked off as pa from any pole p, the the line pa being drawn perpendicular to P_AA. Then pb_1 and ab_1 intersecting in b_1 are drawn perpendicular to P_BB_1 and to B_1T_{AB}. This gives pb_1 the velocity of B_1 and ab_1 the velocity of sliding of one tooth over the other.

Then pb_2 and b_1b_2 intersecting in b_2 are drawn perpendicular to P_BB_2 and to B_1B_2; pb_2 is the velocity of the point B_2. Finally, pc and b_2c intersecting in c are drawn perpendicular to P_CC and to the normal CT_{BC}. This gives pc the velocity of C, and b_2c the sliding velocity of this second pair of teeth over each other. The process may be carried on indefinitely through a whole train of wheel work, however complicated. As a method of finding the velocities throughout such a train, however, it is not a practically useful one, because the

directions of the normals to the touching surfaces cannot be very accurately obtained on the drawing unless the "pitch points" T_{AB}, T_{BC}, &c., are known, and if these are known to start with, the various velocities can most simply be determined from them directly without reference to the touching points.

The point T_{AB} may be looked on as indicating two points, one in the first wheel, which may be called T_A, and the other in the second, which will be called T_B. To obtain the velocity of T_A the triangle pat_a is constructed similar to the triangle P_AAT_A. In this triangle at_a coincides with the line ab_1, and pt_a is perpendicular to P_AP_B. Making a similar construction for the velocity of the point T_B, we find that the point t_b coincides with the point t_a. Thus the points T_A and T_B in the two wheels have the same velocity pt_{ab}, and the point T_{AB} is therefore called the "pitch point." The angular velocities of the two wheels are therefore inversely as the distances P_AT_A and P_BT_B, this being a familiar theorem proved in the ordinary treatment of toothed gearing. Similarly, if pt_{bc} be drawn perpendicular to the centre line P_BP_C to its intersection with b_2c, this pt_{bc} is the velocity of the pitch point T_{BC} of the pair of wheels (BC). If the teeth be so shaped as to give constant angular velocity ratios between the wheels, the points T_{AB}, T_{BC}, &c., in the diagram of the mechanism and the points t_{ab}, t_{bc}, &c., in the velocity diagram remain fixed throughout the periodic motion of the train. It may also be noticed that since

$$\frac{at_a}{pt_a} = \frac{AT_A}{P_AT_A} \text{ and } \frac{b_1t_b}{pt_b} = \frac{B_1T_B}{P_BT_B}, \text{ therefore } \frac{at_a}{pt_a} \cdot \frac{pt_b}{b_1t_b} = \frac{at_{ab}}{b_1t_{ab}} = \frac{AT_A}{P_AT_A} \cdot \frac{P_BT_B}{B_1T_B} = \frac{P_BT_B}{P_AT_A},$$

so that $\frac{at_{ab}}{b_1t_{ab}}$ also measures the ratio of the angular velocity of wheel A to that of wheel B. The condition that the angular velocity ratio should remain constant may thus also be expressed by the condition that the line ab in the velocity diagram, representing the velocity of sliding of tooth over tooth, should be divided in a constant ratio by the fixed point t_{ab}. [This point t_{ab} is only fixed if the angular velocities themselves, as well as their ratio remain constant, the magnitudes of these angular velocities being proportional to pt_{ab}.] Whether this proposition can be utilised in simplifying the practical drawing out of the teeth-profiles, so as to secure a constant velocity ratio, the author has not yet had time to investigate.

Velocity and acceleration diagrams have been completely worked out for the Joy's valve gears used by Mr F. W. Webb on his compound locomotive engines, the gear being differently arranged for the high and low pressure cylinders. These mechanisms are too complicated to be treated without very inaccurate approximation by any other graphic or algebraic process known to the author.

Fig. 1.

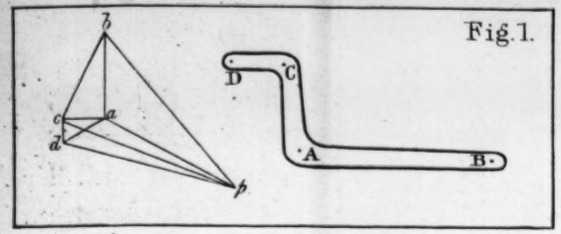
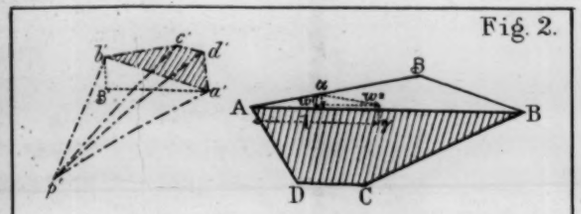


Fig. 2.



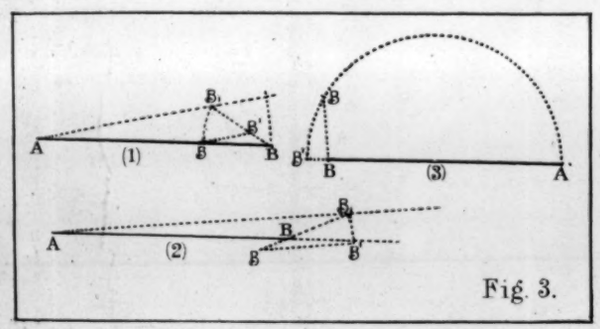


Fig. 3.

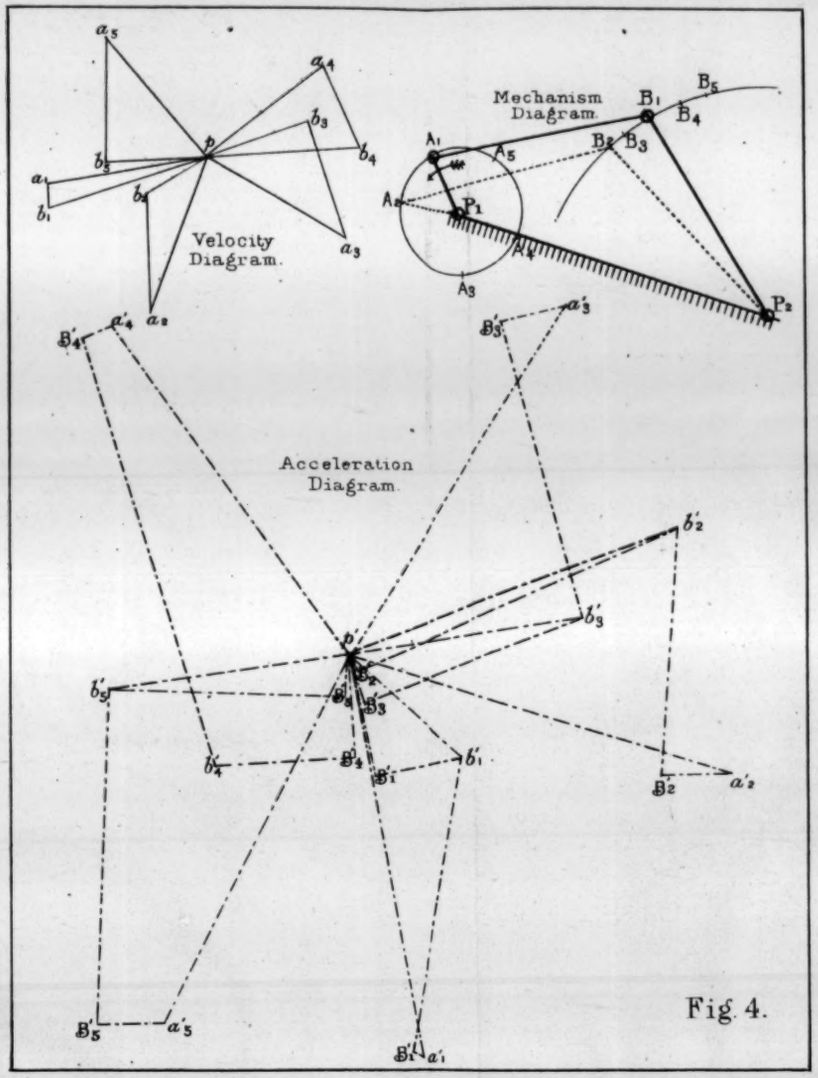
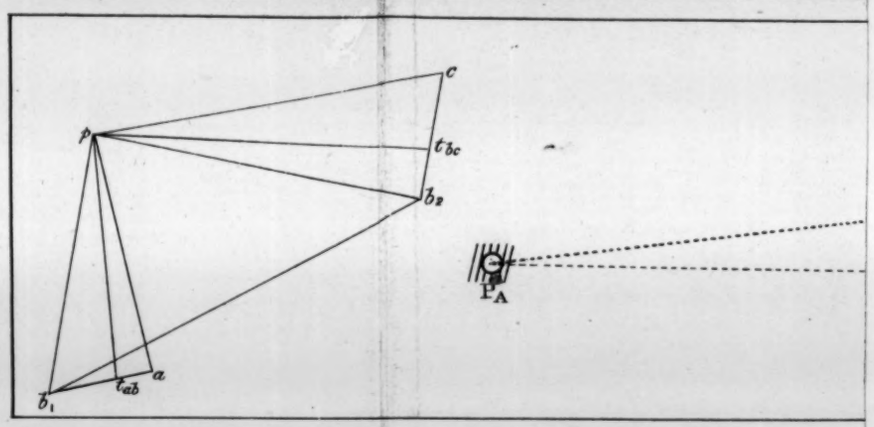


Fig. 4.



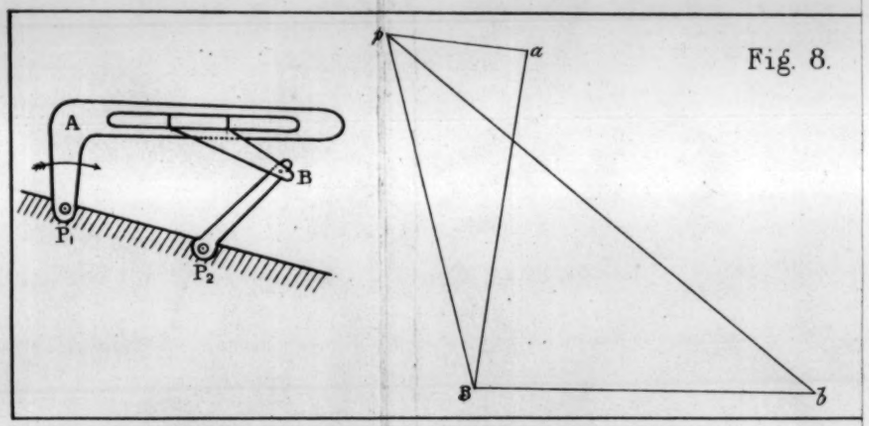


Fig. 8.

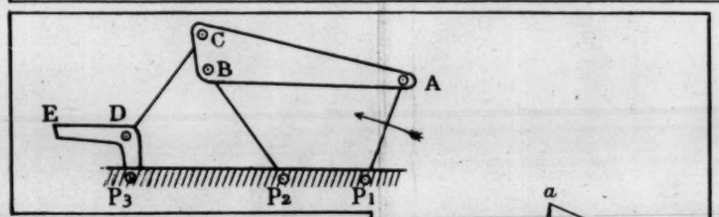
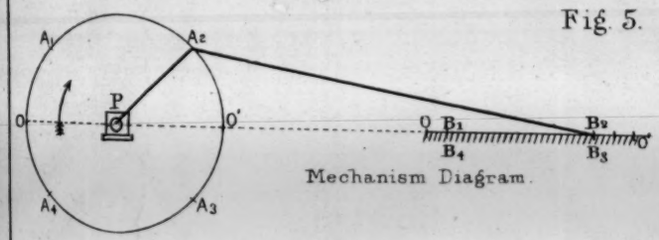
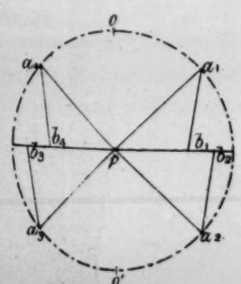


Fig. 5.



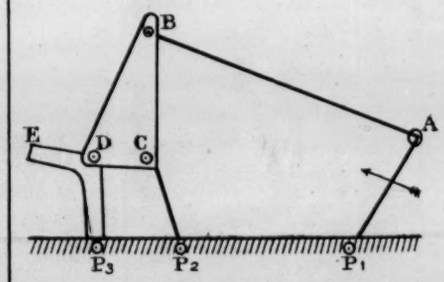
Mechanism Diagram.



Velocity Diagram.



Acceleration Diagram.



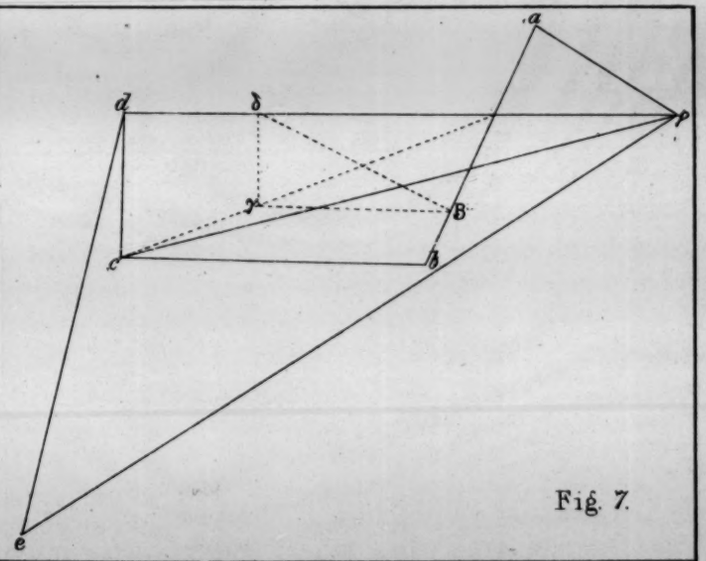


Fig. 7.

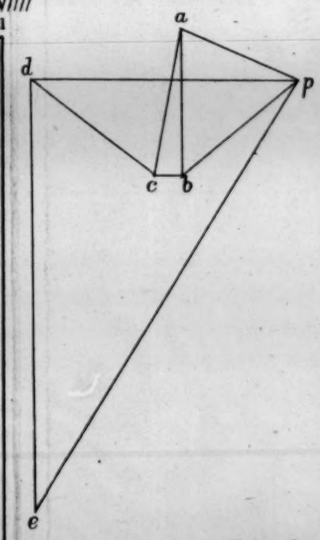
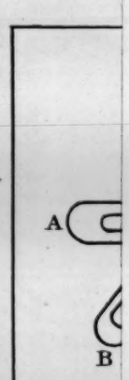


Fig. 6.



GRAPHIC ANALYSIS OF THE KINEMATICS OF MECHANISMS.
DIAGRAMS.

Fig. 1.

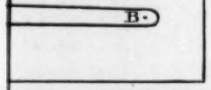
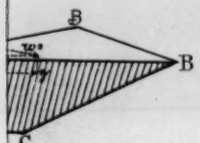


Fig. 2.



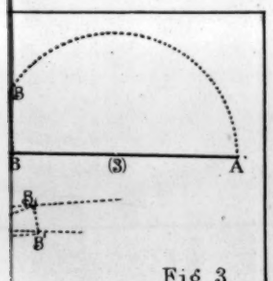


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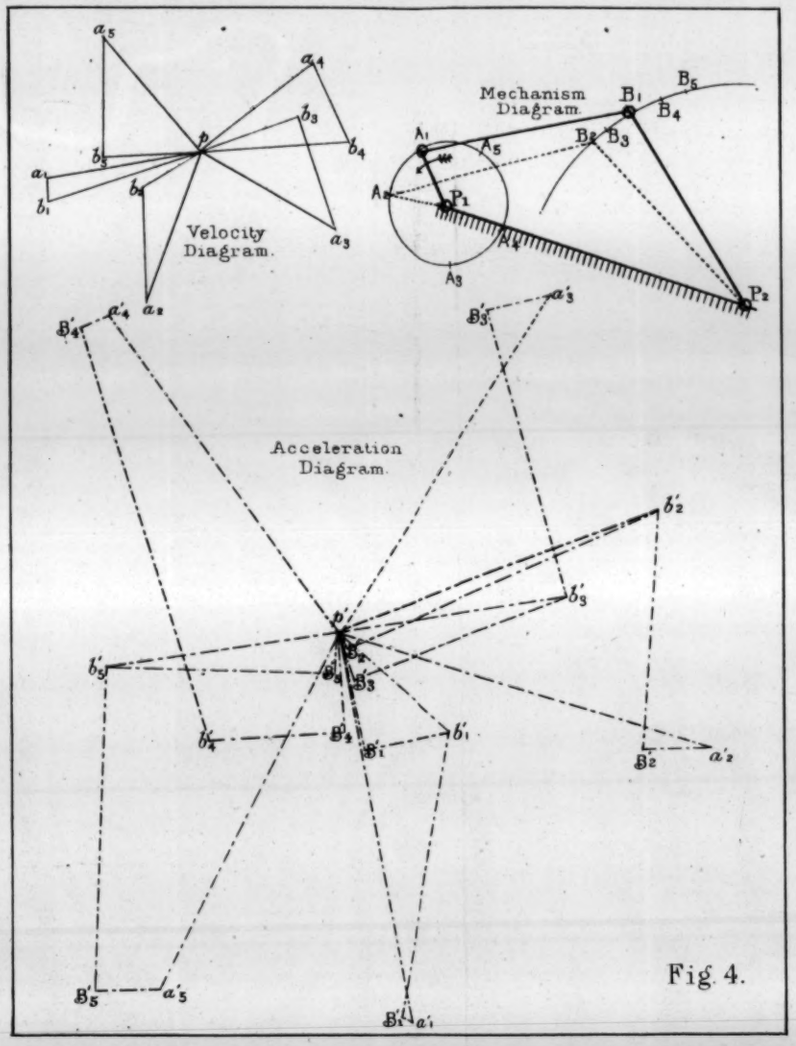
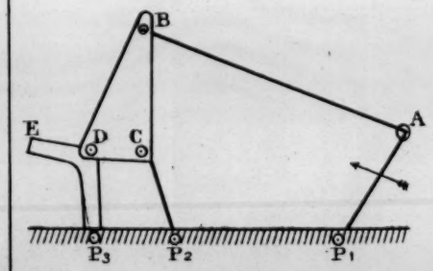


Fig. 4.

Fig. 5.





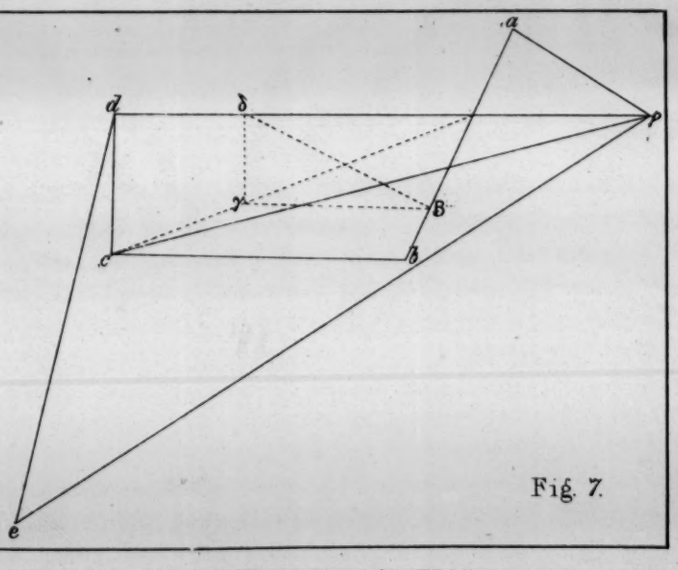
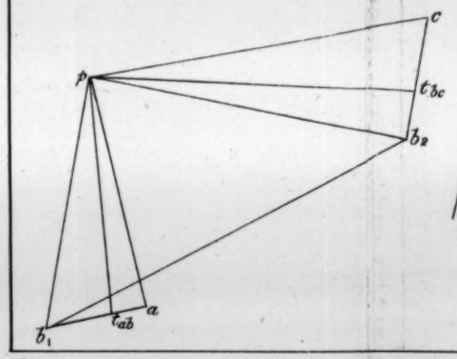


Fig. 7.



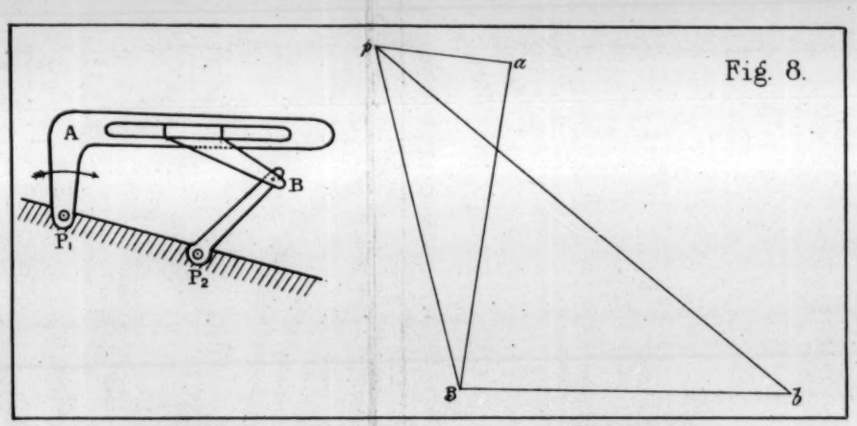
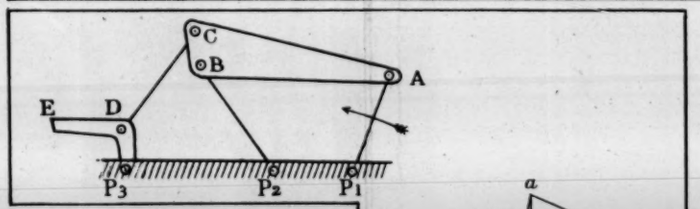


Fig. 8.



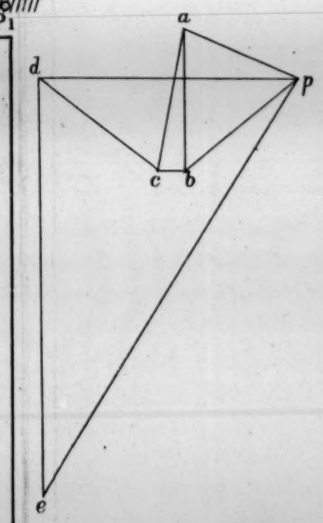


Fig. 6.

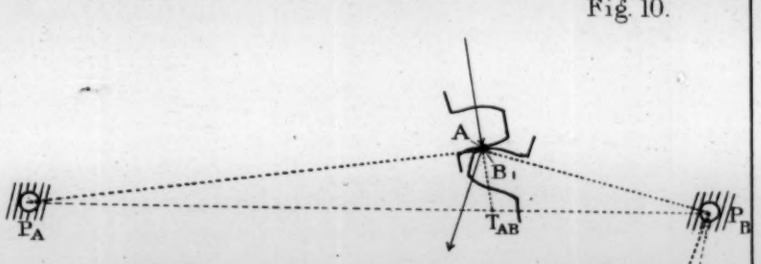
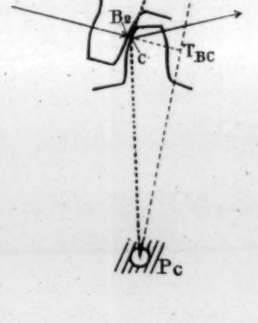


Fig. 10.



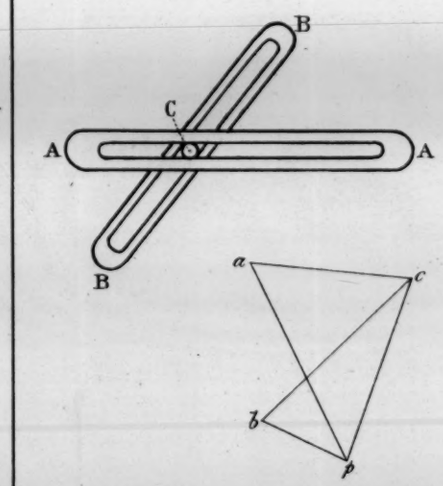


Fig. 9.

Id^t Farlane & Erskine Lith^rs Edin^r

GRAPHIC ANALYSIS OF THE KINEMATICS OF MECHANISMS.
DIAGRAMS.

XXIX.—*The Visual, Grating and Glass-lens, Solar Spectrum* (in 1884).

By C. Piazzi Smyth, F.R.S.E., and Astronomer-Royal for Scotland.

(Plates LXXXIII.–CXLIII.)

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Part I.—The Observations; their objects, and the mode of compassing them.

Throughout the year 1884 the sun was seen over most countries under peculiar atmospheric circumstances; and these, instead of being confined to low altitudes, were never more conspicuous than during the summer of the year, and noon-tide of each day, and in the clear air on mountain heights of every country, whenever the sky was more or less free of actual clouds.

On such occasions then, the usual phenomenon to be noticed by the eye, was, that nothing like blue sky could be witnessed near the sun. But in place of that, there was a broad glare of whitish light extending for several degrees around the luminary; and beyond that range, or over 20 degrees distant from him, there spread a wide reddish haze, passing into purple, and at greater distances into blue, but nowhere a very decided and deep blue sky.

That the medium producing this appearance was terrestrial rather than Solar, was indicated by similar effects being seen about the full moon. But that its locality must have been far higher than the ordinary clouds was still more conspicuously proved by the said clouds always appearing in front of, or backed by, the peculiar reddish glare; and then showing their own cloud-tints, greenish-white on their illuminated edges, and blue-gray on their shaded sides, in most pronounced chromatic relief.

The upper air, to produce any such effect, must at the very least have been filled with far more than the average amount of those minute dust particles, which are always floating about there in greater or less quantity far above the level of all ordinary massive clouds of watery vapour. And though some of the extra amount of this higher dust may have been derived from several other sources, yet the general opinion of most men of science in

most nations appears now to be, that by far the greater part of it must have been supplied by the widely extended volcanic eruptions of 1883, in Australia, in Alaska, but chiefly at Krakatao in the Indian seas.

In each of those three cases, clouds of matter went up, and mud, stones, and coarse dust came down, both speedily and within such immediate proximity of each volcanic vent as to testify unmistakably to their parentage. But in the Krakatao case, if not in the others also, a far finer kind of dust went up very much higher; so high indeed as to be left behind by the earth in its axial rotation; and thus to be seen successively by every terrestrial meridian in the course of 24 to 35 hours; and was recognised to be spreading out sideways widely and rapidly at the height attained.

One of these resultant cases, I believe that I saw from the Calton Hill in December 1883 when, after sunset, a brilliantly illuminated display of broad, thin, and nearly uniform cirrus cloud, stretching at one moment apparently through the whole heavens from south, through the zenith to north,—went down with remarkable speed, and in one piece, towards the west, as though it had been a curved shutter of the outer sky, pivoting in the south and north points of the horizon, turning rapidly upon them as an axis, and leaving ordinary clouds hanging about in the lower air, amenable only to petty winds blowing this way and that, near the low-down surface of the solid earth.

That any great portion of a volcanic eruption is ever got rid of by being reduced to impalpable powder, projected upwards far above the clouds, and eventually sprinkled in homœopathic dust-rain over all the surface of the globe, seas and continents alike, and found in rain-gauges—was evidently beyond the ideas of geologists in 1850. For then after a valuable paper read before the Royal Society, Edinburgh, by one of its most respected Fellows, on the volcanic features of the Alban Hills near Rome,—wherein the learned author enlarged on the terrific intensity of the ancient explosions which had *blown out* the once stupendous rock-contents of their now deep, hollow craters, a gray-headed geologist present inquired with painful care, what had become of that mass of ejected rock? Was it to be found close outside the craters, or at what distance therefrom, and in what sizes and shapes of blocks? Whereupon the really able author of the paper became confused, admitted he had made a mistake, and ought to have said that the supposed blown-out rock-masses had really fallen in; and that was the reason why they were not to be found lying about in big, recognisable portions outside.

But with the ultimate Krakatao volcanic ejection which went up, it is said, as a mighty dust cloud, formed of half the mountain's bulk, to a height of forty miles, and under such compelling force as to carry its electrical charge, as due to the interior of the earth with it, and thereby became endued in its every atom with a power of floating perhaps for years above the terrestrial planet,—did

any gaseous matter, and if so, of what kind and in what quantity—accompany the ultra triturated dust of material shot up from earth's furnaces far beneath the sea? In the red prominence explosions of the sun, which are far more like the gigantic Krakatao upshoot, than are any of the cannon-ball experiments at Woolwich, gaseous matter is conspicuous enough. But in the case of any earthly volcanoe, such a conjectured material has never yet been proved for its superior manifestations. For though many persons may—like the elder Pliny when he ventured too near Mount Vesuvius at its classic eruption in A.D. 79,—may, I repeat, have perished from noxious gases exuding out of the lower flanks of the mountain,—those cases do not seem to have excited much curiosity as to whether such volcanic gases are chemically different from those already known to exist in the atmosphere, and are ever ejected in such quantity and with such force as to form a notable part of the explosion in the higher regions of the air.

The spectroscope however is, with the assistance of transmitted light, an infallible test as to whether any particular medium in the upper air, dense enough to colour the rays of the sun when shining through it,—is formed of solid insoluble particles only, or is composed of a true but strange gas, unnatural to our atmosphere. For in the former case the solar spectrum will be merely, but continuously dulled from one end to the other,—while in the latter some remarkable localised spaces or transverse lines of absorption, in addition to all those already known as Fraunhofer lines, whether of solar or terrestrial origination, may be expected to be met with.

Hence a solar spectroscoping in 1884, besides its own proper uses for cosmical knowledge, might be expected to have some further special interest connected with our own earth, *i.e.*, if conducted with sufficient dispersive and magnifying power; and unprecedented power of the former kind has been lately given to many scientists by the magnificent diffraction gratings prepared by Professor ROWLAND of Johns Hopkins University, Baltimore, on his novel and admirable ruling engine.

I was among the happy number to receive one of those gratings, with a surface ruled at the rate of 14,438 lines to the inch, over an area of $3{\cdot}5 \times 5{\cdot}0$ inches; but had intended to confine its use to vacuum tube spectra,—until I learned that the mysterious attractions of the invisible, over the visible, especially when brought out by the hasty, labour-saving method of photography, —were leading most of the other donated observers to neglect the visual portion of the solar spectrum, in spite of its beauty, its central character, and the wonderful organs by which the Creator has enabled man to enjoy it.

Without giving up therefore my own eventual hopes and intentions on artificial spectra, or interfering in the slightest degree with the recondite proceedings of the greater physicists on the invisible extensions at either end of the solar visible spectrum,—I proceeded through the autumn, winter, and

spring of 1883–4, with the valuable aid of Messrs T. Cooke & Sons, of York, to adapt my example of a Rowland's grating for use in a large wood and metal apparatus. This was of somewhat unusual form, carried object glasses 4 inches in diameter, employed a magnifying power of 67 times linear on the inspecting telescope, and was specially adapted for securing differentially, but with remarkable rapidity, a highly magnified record of the whole visual solar spectrum, whatever that might prove to be at the epoch.

Something however still more than one single record of such a spectrum appeared due to the science of our time; for such science has established most profoundly, that there is no scientific subject of numerical mensuration whatever, wherein any man, or any number of men, can do more, when they aim at exactitude, than arrive within certain limits of probable error as to what the truth may be. As these limits too may be very various for the different lines of the spectrum, of which there are several thousands,—I determined, if I could observe one spectrum well, to follow it up by a second, and even third time of going through the whole of it; with the view of eventually bringing the three records together in such a manner as to facilitate their comparison, and rather provoke, than silence, criticism on every line.

But could three such extensive spectra be successively, as well as completely, observed micrometrically by the eye and hand of one observer in the course of two months only of an ordinary North-British summer season?

Not unhappily in Edinburgh; where, over and above the general cloudiness of the summers, the fearful increase of coal smoke in the air, during these latter years of unexampled growth of its happy population in numbers, wealth, and abundant burning of coal without consuming the smoke thereof,—has vitiated the city's atmosphere to a degree quite prohibitive at last of any of the nicer observations of Astronomical Physics.

Could, however, the desired end be obtained by visiting the South of England, profiting by itsusually sunnier summers, the absence of coal fields, and avoiding the larger cities?

That was what I proposed to try; and after some deliberation pitched on Winchester. Once indeed the ancient metropolis of England under her Saxon Kings; but now is it so shrunk within its former magnificent bounds, and so lowly withal, that with the exception of its Cathedral, St Mary's College, and a new town-hall by Gilbert Scott—the rest of its generally diminutive, flint-walled houses might almost all be packed away, even hid, within our George Street. Eminently neat and decorous however is modern Winchester; with no manufactories to speak of, save a few small ones for brewing beer, or preparing Hampshire bacon and flower honey. A useful country town evidently for farmer's supplies, and yet grandly historic. Surrounded by healthy, open, undulating chalk downs, with umbrageous trees and charming gardens in their hollows;

sky-larks and wood-peckers the principal birds. Noble landscapes of English kind on every side, teeming with well preserved objects of even higher than Saxon antiquity. Roman roads shooting straight over hill and dale, and *tumuli* of aboriginal Britons far older still. While the primeval soil itself, wherever opened, shows virgin white ; and nothing gets smirched in that fair champaign with either smut, or soot, or any appreciable coal smoke.

In the largest upper chamber therefore, of a new country house, by name "Kurn Hattin" (for every house there, even in the town streets seems to have a name) and about two miles North of Winchester, which my Wife and I engaged for the time, the rather unwieldy spectroscope was set up, with its heliostat looking out of a window towards the South-east ; and where, when clouds permitted, the sun could be conveniently commanded at the summer solstice from 10 A.M. to 1 P.M., at an average altitude say of 45°. Suitable therefore for both solar originated lines, and those produced by the higher telluric atmosphere whether natural or adventitious.

Seldom however, through the two months of observation, June and July, did the far too frequent clouds permit of anything being seen except themselves ; and little would have been accomplished unless by utilising every moment of occasional or even partial break ; and sometimes even by observing through the thinner clouds, though that was very untoward for securing the fainter lines. At the same time the heliostat, employed for bringing the solar rays whenever they were visible, to the grating, being only the same rude, hand-worked affair I had taken before to Lisbon and Madeira, required the services of an assistant in rapid observation. Well too had I been assisted therein at both those foreign stations, by my Wife's patient enthusiasm, and enduring skill. But through almost the whole of our stay at Kurn Hattin she was unfortunately laid up with severe, even dangerous illness ; and the observing conditions would have gone too heavily against me, but for a circumstance as unexpected, as it proved appropriate, grateful, and effective.

This was,—that the country-house next to us, was occupied by Colonel KNIGHT, an officer recently retired after a long and honourable period of active service in tropical climates. But now he was prosecuting to his heart's content Meteorology of the most careful and conscientious kind,—while he rejoiced also in the possession of an Astronomical Observatory built by himself, furnished with both Transit Instrument and magnificent Equatorial by Cooke, and was both F.R.A.S. and F.R.M.S.

This gentleman then most obligingly gave me the utmost aid in working the heliostat. For whenever there was the slightest chance of seeing the sun, he would come over to Kurn Hattin, sit out the most perverse clouds until sunshine broke at length ; and then he would keep any solar image visible at all,—and more particularly the same colour region in the preliminary spectrum

which he knew I was working at in the subsequent spectrum,—steadily on the collimator's slit, for as long as I could make effective use of it.

This important assistance so greatly increased my powers for work, as to enable me after all just to accomplish the three spectra, pack up the instrument, and return to Edinburgh within a day of the date required.

METEOROLOGICAL APPENDIX TO PART I.

The originals of the following Meteorological observations, so important as a guide to water-gas lines, and their varying manifestations from day to day, though telluric, in the *Solar* Spectrum, have been kindly handed to me by Col. KNIGHT; and were taken by himself at his Observatory, within a few yards of Kurn Hattin, Harestock, Winchester,—in

Latitude $= 51° 4' 43''{\cdot}4$ N.

Longitude $= 0^h 5^m 21^s{\cdot}53$ W.

Height of cistern of barometer above mean sea-level = 316 feet 7 inches.

The daily time of observation being 9^h A.M., and the means referring always to that hour except in the case of self-registering instruments; whence,

in June, Mean Barometric Pressure, reduced to sea-level and Temperature 68°, = 30·145 inches

1884. Mean Temperature of Air in shade, ... = 58°·3 F.
Mean of Self-registering Maximum Thermometer, ... = 65°·9 F.
Mean of Self-registering Minimum Thermometer, ... = 48°·1 F.
Mean Semi-daily Range of Temperature in shade, ... = 8°·9 F.
Mean Depression of Wet-bulb temperature in shade, . . . = 4°·7 F.
Water-gas in a cubic foot of Air, computed, ... = 4·0 grains
Mean Relative Humidity (Saturation = 100), computed, . . . = 73·0
Water-gas still required to saturate a cubic foot of Air, computed, . = 1·5 grains
Total Sunshine, by Recorder, in A.M. hours, ... = 80 hours 45 minutes
Total Sunshine, by Recorder, in P.M. hours, ... = 92 hours 14 minutes
Wind, Measured mean miles per hour, ... = 6·74
Wind, Direction E. to W. as 3 to 6; and S. to N. as 4 to 16, . = N. by W. nearly

and in July, Mean Barometric Pressure, reduced to sea-level and Temperature 68° F., = 30·064 inches

1884. Mean Temperature of Air in shade, ... = 62°·2 F.
Mean of Self-registering Maximum Thermometer, . . . = 68°·6 F.
Mean of Self-registering Minimum Thermometer, . . . = 52°·5 F.
Mean Semi-daily range of Temperature in shade, . . . = 8°·0 F.
Mean Depression of Wet-bulb Temperature in shade, . . . = 4°·3 F.
Water-gas in a cubic foot of Air, computed, ... = 4·6 grains
Mean Relative Humidity (Saturation = 100), computed, . . = 76·0
Water-gas still required to saturate a cubic foot of Air, computed, = 1·6 grains
Total Sunshine, by Recorder, in A.M. hours, . . . = 60 hours 38 minutes
Total Sunshine, by Recorder, in P.M. hours, . . . = 84 hours 37 minutes
Wind, Mean measured miles per hour, ... = 8·24
Wind, Direction, E. to W. as 2 to 10; and S. to N. as 14 to 3, = S.S.W. nearly.*

* From observations taken by my friend, Mr RAND CAPRON, F.R.A.S., at Guildoun, Guildford,

THE DAILY OBSERVATIONS ARE AS FOLLOWS :—

Date. 1884		Hour.	Barometer reduced to Sea-level, and Temp. 68° F.	Temperature of Air in Shade °F.	'Depression of Wet-bulb Thermometer °F.	Water-gas in Cubic Foot of Air.	Humidity, relative, Saturation=100.	Water-gas still required to Saturate Cubic Foot of Air.	Rainfall.—Depth in Inches.	Sun-shine Recorder. A.M.	Sun-shine Recorder. P.M.	Wind. Miles per Hour.	Wind. Direction.
		A.M.	Inches.			Grains.		Grains.		H. MIN.	H. MIN.		
June 1.	☉	9	30·103	54·2	6·7	2·8	60·	1·9	...	1 01	2 45	5·84	S.S.W.
,, 2.	☾	...	29·736	57·3	5·8	3·4	65·	1·8	...	2 34	3 38	8·87	S.
,, 3.	♂	...	29·625	55·8	5·0	3·5	70·	1·5	0·03	0 00	0 00	9·63	N.E.
,, 4.	☿	...	29·870	50·2	1·7	3·5	87·	0·6	·20	0 00	0 38	7·58	N.
,, 5.	♃	...	29·931	53·4	2·4	3·8	83·	0·8	·06	0 00	1 24	6·72	N.W.
,, 6.	♀	...	29·872	55·0	4·6	3·5	72·	1·4	·95	1 14	2 29	7·59	W.N.W.
,, 7.	♄	...	29·632	46·7	1·3	3·4	92·	0·3	·03	0 00	2 11	10·51	N.N.E.
,, 8.	☉	...	29·908	52·4	3·2	3·5	79·	0·9	·20	0 44	0 05	11·05	N.N.W.
,, 9.	☾	...	29·993	50·3	3·7	3·0	75·	1·1	...	0 08	0 32	7·85	N.N.W.
,, 10.	♂	...	30·199	54·2	4·8	3·3	69·	1·4	...	1 51	1 09	7·69	N.N.W.
,, 11.	☿	...	30·296	54·3	1·0	4·4	93·	0·3	...	0 00	0 00	4·26	S.W.
,, 12.	♃	...	30·413	62·0	3·7	4·6	79·	1·4	...	4 57	6 49	6·64	N.
,, 13.	♀	...	30·399	66·6	6·7	4·8	65·	2·5	...	6 04	4 59	2·58	S.W.
,, 14.	♄	...	30·347	58·9	3·8	4·3	76·	1·3	...	2 46	6 42	8·22	N.
,, 15.	☉	...	30·414	55·3	4·7	3·5	72·	1·4	...	2 26	1 38	10·09	N.
,, 16.	☾	...	30·321	52·4	2·7	3·5	81·	0·9	...	1 21	2 59	7·84	N.N.W.
,, 17.	♂	...	30·279	54·6	3·3	3·9	80·	1·0	...	0 00	0 20	7·96	N.W.
,, 18.	☿	...	30·293	59·3	4·8	4·0	71·	1·6	...	1 52	0 09	4.93	N.W.
,, 19.	♃	...	30·341	60·1	5·6	4·0	68·	1·9	...	3 09	4 00	3·66	N.N.W.
,, 20.	♀	...	30·299	62·6	4·9	4·6	72·	1·8	...	5 34	2 51	3·80	N.N.E.
,, 21.	♄	...	30·306	60·0	4·2	4·4	76·	1·4	·02	3 59	1 53	5·06	N.E.
,, 22.	☉	...	30·262	63·4	7·2	4·0	63·	2·4	·01	5 25	1 05	5·07	N.W.
,, 23.	☾	...	30·171	60·7	5·6	4·2	70·	1·9	...	5 08	6 08	7·59	N.E.
,, 24.	♂	...	30·105	62·2	8·2	3·6	58·	2·6	...	4 15	0 18	4·69	N.N.W.
,, 25.	☿	...	30·124	61·1	2·2	5·2	88·	0·8	...	1 52	6 43	7·89	N.W.
,, 26.	♃	...	30·283	65·8	9·8	3·7	52·	3·3	...	6 56	6 39	4·76	S.W.
,, 27.	♀	...	30·236	68·4	7·3	5·0	63·	2·5	...	6 12	6 41	4·64	S.S.E.
,, 28.	♄	...	30·277	73·2	9·7	4·9	55·	3·9	·73	5 30	6 38	4·59	S.E.
,, 29.	☉	...	30·105	56·9	0·8	4·9	94·	0·3	...	1 24	6 13	7·29	E.
,, 30.	☾	...	30·209	61·8	4·8	4·4	72·	1·8	...	4 23	4 38	7·22	W.

Surrey,—projected in graphical curves on compendious table-forms, and then photographed by himself,—it would appear that these two months, June and July of 1884, were peculiarly unfortunate for sunshine. For not only was the preceding month of May bright with frequent sun, but the following month of August was the brightest and sunniest month of that, or any name which had occurred in the South of England for years.

And yet it would have proved dangerous to trust to that precedent for another campaign, as in the very next year (1885), it was the month of July that proved to be the most admirably sunny ; and to a degree far beyond both May and June on one side of it, and August and September on the other. —*Subsequent Note.* C.P.S.

AND FOR JULY—

Date. 1884.		Hour.	Barometer reduced to Sea-level, and Temp. 68° F.	Temperature of Air in Shade °F.	Depression of Wet-bulb Thermometer °F.	Water-gas in Cubic Foot of Air.	Humidity, relative, Saturation=100.	Water-gas still required to Saturate Cubic Foot of Air.	Rainfall.—Depth in Inches.	Sun-shine Recorder. A.M.		Sun-shine Recorder. P.M.		Wind. Miles per Hour.	Wind. Direction.
		A.M.	Inches.			Grains.		Grains.		H.	MIN.	H.	MIN.		
July	1. ♂	9	30·310	62·1	4·0	4·7	77·	1·5	...	1	44	6	21	6·81	S.W.
,,	2. ☿	...	30·280	64·7	6·4	4·5	66·	2.3	...	4	58	6	48	4·72	S.E.
,,	3. ♃	...	30·115	70·7	7·0	5·4	65·	2·9	...	6	45	4	21	2·33	S.S.E.
,,	4. ♀	...	29·998	70·3	7·0	5·2	65·	2·8	...	3	40	6	08	2·96	S.
,,	5. ♄	...	30·021	65·9	6·0	4·8	68·	2·2	·07	0	00	2	04	5·96	S.
,,	6. ☉	...	30·054	61·6	3·4	4·9	77·	1·3	·03	3	06	2	08	5·11	S.W.
,,	7. ☾	...	30·080	64·2	5·5	4·6	67·	2·0	·01	3	14	6	47	10·88	S.
,,	8. ♂	...	30·005	63·9	4·5	5·0	74·	1·6	...	3	02	5	04	6·62	N.E.
,,	9. ☿	...	29·935	65·6	3·7	5·6	79·	1·4	·02	0	18	3	32	5·94	S.
,,	10. ♃	...	29·737	62·9	3·4	5·0	79·	1·4	·13	0	36	0	01	4·72	S.S.W.
,,	11. ♀	...	29·856	62·4	6·7	3·9	62·	2·3	·87	3	50	0	28	10·36	S.W.
,,	12. ♄	...	29·956	60·4	1·4	5·3	91·	0·5	·19	0	45	1	12	10·06	S.S.W.
,,	13. ☉	...	29·962	72·1	8·2	5·3	61·	3·2	·01	4	58	1	57	8·09	S.E.
,,	14. ☾	...	30·063	61·3	2·5	5·0	84·	1·0	·17	1	27	3	17	13·54	S.W.
,,	15. ♂	...	30·034	60·5	0·6	5·8	96·	0·2	·24	0	00	0	41	14·35	S.W.
,,	16. ☿	...	29·797	59·4	1·7	5·0	90·	0·6	...	0	02	6	34	14·40	S.W.
,,	17. ♃	...	29·858	62·2	3·8	4·7	77·	1·5	·01	1	27	4	47	14·33	S.W.
,,	18. ♀	...	30·155	60·5	6·7	3·8	64·	2·2	...	3	31	0	00	11·61	W.
,,	19. ♄	...	30·245	58·9	7·0	3·5	61·	2·1	...	4	02	5	36	7·94	N.W.
,,	20. ☉	...	30·214	58·7	3·3	4·5	80·	1·1	...	1	52	1	52	4·49	S.E.
,,	21. ☾	...	30·055	60·3	3·3	4·6	80·	1·2	...	0	00	2	32	3·43	S.W.
,,	22. ♂	...	30·135	62·9	4·0	4·9	77·	1·5	·04	0	45	0	14	10·73	W.S.W.
,,	23. ☿	...	29·996	59·6	0·9	5·4	94·	0·4	·05	0	12	0	02	12·14	S.W.
,,	24. ♃	...	29·862	59·2	5·6	3·8	68·	1·8	·13	2	35	2	01	10·12	W.
,,	25. ♀	...	30·042	58·3	4·9	3·8	71·	1·6	·08	1	57	3	59	9·38	N.
,,	26. ♄	...	30·254	53·4	3·8	3·4	75·	1·1	·15	0	15	0	12	5·87	W.
,,	27. ☉	...	29·925	58·4	3·2	4·5	81·	1·1	...	1	58	2	29	13·82	W.S.W.
,,	28. ☾	...	30·245	59·0	7·8	3·2	57·	2·4	·07	1	50	0	01	7·97	N.
,,	29. ♂	...	30·164	64·6	3·7	5·4	80·¾	1·4	...	0	13	0	03	7·22	W.N.W.
,,	30. ☿	...	30·302	65·9	4·2	5·5	78·	1·5	...	0	10	0	47	3·71	S.W.
,,	31. ♃	...	30·318	57·6	0·1	5·4	99·	0·0	...	1	27	2	38	3·81	S.S.E.

PART II.—REDUCTION OF THE INSTRUMENTAL, TO A WAVE-NUMBER, SCALE.

The shape in which the Winchester Spectrum work was brought to Edinburgh on July 30th, consisted in three packets of seven lengths of paper each; every such length containing 19 to 20 parallel, but consecutive revolution strips, and each strip, 14 inches long, holding on an average the recording marks for about 50 Fraunhofer lines. So that each of the three spectra might be formed into a continued length of nearly 160 feet of paper, holding something between 6 and 7,000 symbolic notings in its course, to indicate various characteristics besides the very important one of angular place, by micrometric screw measure, of as many solar, spectral, "fixed" lines.

The first step in reduction consisted in transferring with ruling pen and square all these fiducial markings at their several distances apart, to large engraved sheets, furnished with scales of nearly equal length to that of the Micrometric apparatus, but with much more space above and below whereon to develop the condensed symbology of the original pencillings, and introduce dates and notes for every day's work. Each of the three spectra was thus treated in perfect independence of the others, and the third one had further still been observed in a very different manner to the first and second. For while they had the benefit of a collimator 70 inches long, the collimator used for the third, though with the same diameter of objective, was only 35 inches long; while the cone of rays from the preliminary condensing lens of the heliostat was now still further condensed and shortened by a supplementary lens.

Greater brightness of spectrum was hoped for by this concentration of Sunlight on the slit, but was not obtained; and in place of it only a third spectrum very like the first and second;—no one of them being perfect; and the mean of the three, probably better than any one taken by itself alone.

The amounts of such residual failings in each set of measures, though very small in themselves and hardly to be perceived in most spectrum work, was nevertheless, on the grand scale here attempted, quite sufficient to prevent the records, though derived from a Diffraction Grating, being always read off implicitly as a continuous scale of wave-lengths. I determined therefore to look upon them as varying differential measures, to be trusted only for short micrometric runs; while an absolute scale was prepared for them all, by referring the places of their chief lines to ANGSTROM's celebrated Normal Solar Spectrum Map,—assisted where necessary by the numbers recorded in the much later works of MM. VOGEL, CORNU, FIEVEZ, THOLLON, and Professor YOUNG, U.S. Am.

Their scales however being for Wave-lengths in terms of the French Metre,—I had to reduce their figures to Wave-number *per* British Inch, for the reasons stated in my paper lately printed by the Royal Society, Edinburgh, entitled "Micrometrical measures of Gaseous Spectra." While finally I entered the leading divisions of such a scale, to the number of 600 for each spectrum, upon the sheets of pen and ink work,—after having obtained the rates of variation by the usual method of projecting the places of known lines on paper ruled transversely with the Micrometer scale, and drawing curves, through the points of intersection. The insertion of nine marks of nearly equal subdivision between every pair of the original 600 then followed, and gave each spectrum by itself a Wave-number scale with as many as 6000 fiducial steps marked and numbered; but on a continually contracting, or conical, scale in passing from Red to Violet: as well as totally different when, for some parts of the spectrum,—as the very earliest of the Red,—the first order of the Grating was substituted for the second order, or that usually observed upon.

These 6000 fiducial steps had, of course, next to be transferred to sheets representing a Wave Number Scale of equal parts; and in order that the ultimate comparison of different authorities might be as instant as possible, these latter sheets must be of a collective character and contain all the authorities, at each point, one under the other.

To this end, 60 plate forms of a long or double quarto size were prepared, each carrying 500 units of Wave-number scale, as adapted to a spectrum now of only 80 feet in length, and in strips one under the other five times repeated. In the three lower strips the three Winchester spectra were entered by measure; and in the two upper, the standard tests and critical references.

The topmost of these two reference strips, excepting for the three first sheets of the series, wherein KIRCHOFF's celebrated spectrum was followed, could not but be devoted to ANGSTROM's Normal solar Spectrum; not only on account of the accuracy of his absolute places, and his long priority—but for his, and his friend M. THALEN's invaluable chemical equivalents of solar lines; and as they were now stretched out on these new sheets to about ten times the length they occupied in the original Upsala Atlas,—I was much pleased to find that a certain amount of microscopic confusion which has been complained of by some persons there, was completely corrected.

The second however of the reference strips was confined both to solar lines and to the most advanced maps of them by any of the later observers, as Professor VOGEL, M. FIEVEZ, M. CORNU, M. THOLLON, Professor YOUNG of Princeton, and Professor ROWLAND, Baltimore, U.S.,—duly naming each of those great authorities whenever cited.

But it is now time that I should render due thanks, and give proper praise to Mr THOMAS HEATH, First Assist. Astron. R. Obs. Edin., for the very great help he has afforded me in this section of the work. For not only has he, in the long conical sheets of the three Winchester spectra, inserted the nine sub-dividing lines and their numbers between each pair of my 600 preliminary points thrice repeated; but he has had the whole responsibility of copying, introducing, and greatly enlarging at the same time ANGSTROM's celebrated Normal Solar Spectrum with all its chemical references in clearer guise, into the topmost horizontal strip of each of the final and collective plates;—besides doing the same for all the consecutive selections of various spectra introduced into the second reference strip,—where too the various depths of lithographic tints employed by some of the authorities, could not have been reproduced certainly and satisfactorily in printable form, except by such admirable and clear-lined penmanship as Mr HEATH's.

Part III.—Graphical representation in place of printed numbers alone.

The final step, that of transferring into the three lower strips of each of the 60 plate forms above alluded to, every line of each of the Winchester Spectra from the long sheets with the conical scales—had of course to be carried out rigidly by myself; and as it has also been done on a partly symbolic plan of my own, intended to secure greater trustworthiness in spectrum drawings for the future,—I may as well say a few words upon it at this point.

For the middle of the Spectrum, the ordinary method of representing all the stronger Fraunhofer lines, as vertical and parallel black lines ruled of more or less thickness, but of equal height on a horizontal strip of white paper,—such a method, I say, is just about as good a one as can be desired; for excepting colour, which has been hitherto *tabooed* in all high class Solar Spectrum Maps, the white paper stands expressively enough for the brilliant continuous part of the Spectrum of the Sun, and black ink lines also well represent the darkness of sharply-defined Fraunhofer lines seen thereon.

But when exactly the same method is carried out to each end of the Spectrum, where of course the continuous spectral light of the hitherto luminous back-ground in Nature at last vanishes in darkness, and no black lines can be seen clearly, in a quite, or even an almost, dark field,—such method I would beg to point out, misleads those who use such maps, grievously. For they are led to believe that there is just as much continuous spectrum light between, or as it almost looks behind, the lines of the preliminary band of Great A, as there is between those of Great B, or of the Alpha band; and such reading students may form very erroneous estimates of the probable error attending on the observations of place for the first named lines, or on the distribution of lines, their thickness and the degrees of definition prevailing among them.

To meet this imperfection in previous maps, I have introduced into mine, towards each end of the spectrum, a black shade running along the lower side of the otherwise white horizontal strip, and gradually rising in it as the spectral light fails; until, when that ceases any longer to be visible, the black shade has risen to the top of the horizontal white strip, and eclipses it from that place onwards. Hence at any intervening point between the full height of the white strip near the middle of the spectrum, and its final extinction at either end, readers may judge of the degradation of the light, by the comparative heights of the black shade below and the white paper above it; or they may imagine the sort of gray that would be produced over the full height of the strip, by smearing upwards, though but approximately, the amount of black contained in that part which is so coloured by the shade below.

So much then for the strength of the illumination of the back-ground of continuous spectrum light, whereby alone any Fraunhofer lines can be distinguished at all. But amongst Fraunhofer lines themselves, there are very great differences ; and while there is nothing so easily imitated or represented by merely drawing a sharp, simple line with a ruling pen and black ink on white paper, as a strong, well-defined, Fraunhofer line,—there are all sorts of deviations from such an ideal in the course of the Solar Spectrum. For there, every experienced observer knows so abundantly, that besides lines thick and lines thin, there are lines of various degrees of paleness, and of various degrees of sharpness, as well as sometimes of even extravagant haziness ; and all these are physical facts which should be expressed to some extent,—though minute accuracy does not stand with them on the same high level of importance as with accuracy of place in the horizontal scale.

Hence with those two great "Dioscuri" leaders of modern Spectroscopy, KIRCHOFF and ANGSTROM, the former's map is not so popular now as it once was, —and partly because the method he adopted of indicating both paleness and thinness of some lines, by printing them in from pale tint stones amongst black lines previously printed from another stone, both sacrificed accuracy of place, and produced very ultra ideas of colour as well as paleness. While Angstrom's map, which printed every line from one stone, with one inking, and sought to give thinness and paleness by exquisitely fine engraving only,—still holds its own among Spectroscopists with remarkable power and tenacity.

Yet his is not a perfect method, for it cannot show such an undoubted existence as is occasionally met with, in the shape of a *broad* Fraunhofer line of *pale* material. While partly to make up for that graphical weakness as well as some others, the plan of pure engraving has been made the parent of a most widely followed, yet distinctly vicious, system of representing shade, especially pale shade, in the spectrum by thin, close, *vertical* and parallel lines.

Now some shady, nebulous bands to inferior spectroscopes, do undoubtedly resolve themselves into thin lines in a better instrument, but some of them do not, and ought not, in any spectroscope whatever; and even with those that do, the question of importance is to determine, into how many lines, and at what distances apart? Wherefore for an observer who has seen nothing whatever but a hazy, nebulous shade, to represent that in his map by clean, distinct lines of his own invention, drawn just as they would, or ought to, have been drawn, if he had seen veritable Fraunhofer lines in that place, is a species of wilful, scientific misleading which should be tolerated no longer.

I have had no scruple therefore in my own maps, and also in my copies of anything really important from other men's maps, in adopting as a governing principle for representing both paleness, and degrees of haziness in the spectrum, a symbolic method, not only easy of execution but perfectly impossible to be

confounded with any genuine Fraunhofer, or spectroscopic line proper,—and have called attention to the fact, and the principles on which it is based, at the foot of every one of the 60 plates now presented.

These plates are further, though only half the size * of the original records, yet still on so very large a scale, that the places of any lines thereon, despite much roughness in the drawing, may yet be read off to such an accuracy, as not to require any columns of printed numbers to follow. There only remains therefore the propriety, when the plates are so numerous, to devise some easy and effective Index to them and their chief contents.

Part IV.—Indexing by Colour.

The want of something of that kind becomes most evident, when some one line has to be looked for among actual thousands of others, without its exact Wave-Number place being perhaps known beforehand; and not known most probably on account of the Scientist or Student having been accustomed to use some other Spectrum scale, as either French Wave Lengths, or Kirchoff's private Prism numbers, or the devices of some optician.

But no matter what strange, artificial and human devised spectrum scale any one may have been using,—he must also, if an observer, have had Nature's inimitably beautiful, and effective general indexing of spectrum place by *Colour*, before his eyes again and again; till those colours must, if he has a soul, have been impressed involuntarily and indelibly, on the tablets of his heart in thankful admiration of God's glorious Creation. Wherefore such a person's search for any particular lines, guided otherwise by merely the one remaining, self-evident feature, viz., their configuration in black and white,—a configuration which may repeat itself very nearly, and therefore deceptively, many times in the course of the whole spectrum,—will be enormously aided, expedited and rendered more agreeable too, if, knowing beforehand that the group he wants is in the *Green*,—he finds 6 out of the 60 sheets coloured Green, and the rest of them steeped in colours as easily distinguishable from Green as they can well be.

The manner however of introducing this colour into the Winchester work, is again partly symbolic; in so far as, instead of one colour blending insensibly into another, each is inserted in a flat tint, perfectly uniform from beginning to end; but for that very reason, by so much the more easy to be separated by the eye, from either the preceding or the following colour. Nor need this be considered much of a violation of the more important laws of the Natural Spectrum; because, as I have shown several years ago in the *Transactions* of

* This note of size refers to the drawings for the plates. The actual prints, for economy's sake, are only one-third the size.

the R. Soc. Edin. (vol. xxviii.)—the spectrum colours, unlike the Fraunhofer, or "fixed" lines in the solar spectrum, are not fixed and unalterable in spectrum place; but are positively locomotive therein through certain limits, according to the colour and the strength of the light. Hence Colour, though gloriously powerful, can only be, under any method of representation, an approximate indicator of exact spectrum position; and will be most useful, when we employ it on that clear understanding alone.

Dependent then in part on what the chromo-lithographer can accomplish, and what I shall be able to pay for—as the Society is not to be put to the expense of colour,—I have turned to the chromatic plate in my book "Madeira Spectroscopic," and have extracted thence ten well separated and easily distinguishable colours,—extending by equal spaces of 3000 W.N. Units on 6 plates each, through all the visual spectrum depicted as here from 33,000 to 63,000 W. Number place. And I have also described, as well as exhibited, each of those 10 colours, together with an ultra-region at the beginning and end of them in a single collective plate, which I trust will be found all the title-page and index, which the whole mass of the following plates requires.

These plates are numbered, not 1 to 60, but 2 to 61; for the reason, that the No. 1 plate after being finished in MS., was found to contain only one line, and that of no very pronounced character. In the spectrum itself too, it is exceedingly difficult to see, and therefore not capable of much accuracy of measure, so the plate carrying it has been omitted for economy's sake. While finally, at the suggestion of the Secretary R. S. Ed., I have added throughout, to the two upper strips, the scale points of "Wave lengths" in modern French metric terms, adopted by ANGSTROM in the latter years of his life, *vice* the "inches" of his renowned and heroic Scandinavian forefathers.

PART V.—OF VARIATIONS OF TEMPERATURE AND OTHER PROBABLE SOURCES OF MINUTE DISTURBANCE.

On comparing the three Winchester Spectra carefully together, after they were entered, reduced to Wave-number scale, on the final 60 sheets,—I was rather disappointed to find that they did not agree more closely and minutely at every point—whether as regarded (*a*) the exact places and appearances of strong and well-known lines; or (*b*) the existence or non-existence, as well as the exact places, of very thin lines not hitherto generally known of, or recognised amongst most observers.

In matter (*a*) the anomalies were found, not only in the absolute Wave-number places of the sheets of reduction, but in the original instrumental records; so that the simple intervening distances there, in three several cases of certain well-identified lines between great A and great C,—measured, in

mere inches of the paper micrometric record, with these decidedly too broad limits of variation :—

5·90	5·95	6.16
88·24	89·02	88·34
56·76	56·37	56·27

Still, however, being facts of observation, unexplained and unexpected,—I have never scrupled to give the anomalies in *place* thence resulting to any of the spectral lines, exactly as they came out, through all the finished Plates. But in the inferior matter of *intensities* of lines, and where my method of recording was confessedly weak,—I have often used considerable licence in making each of the three records, if certainly of the same line, approximate from their individual, to their mean, value as to strength. This proceeding will enable every reader to identify the same lines much more easily, in spite of not exactly coinciding places. And though this latter kind of discordance is undoubtedly a blemish, yet its full and intrepid insertion may perhaps prove in the end a valuable aid in deducing the limits of probable error for the place of any line, as given in either a single spectrum representation or in the mean of the three.

But in matter (*b*) the immense variations that appear both for place and even existence among the thinnest and faintest orders of Fraunhofer lines are truly surprising and need inquiry before going further.

Some portions of the uncertainties of place, generally, and for all kinds of lines, thick and thin together, are due to the effects of varying temperature on the grating. Not indeed of the absolute temperature, when settled down to something like permanence ;—for that should have been eliminated by the method of reduction and its appeal to M. ANGSTROM'S standard places. But quick changes of temperature, and sudden springings of the apparatus during a rise or fall of temperature are much more difficult to guard against, and are only too likely to occur from the very nature of the case. That is to say, from the direct heating influence of the Sun, condensed by the heliostat on the slit, and thence passed on to the Grating itself;—but acting there, as dependent on the clouds from minute to minute, sometimes for an hour together, sometimes for only five seconds during several hours.

Some of the errors of place in special localities of the spectrum were owing to the want of correctly fixed standards of reference in regions where, until lately, nothing was known to exist. And some again are due to the fragmentary character of the observation opportunities afforded by the too frequent clouds, whereby the time interval between noting two successive and neighbouring lines, may have been prolonged from a second, to an hour, or a day, or even a week ; and a spectrum run which should have been con-

tinuously as well as speedily obtained at one temperature, may have been a slowly accumulated piece of patchwork at several temperatures.

Other portions again have been suggested to be owing to the natural displacement of lines by the rotation of the Sun, when taken from either East or West limb, instead of from the centre of the visible disc. But these effects could only have been exceedingly small; for I had much difficulty in realising anything of that kind to be measurable, when I actually tried the experiment with the apparatus arranged as employed through the whole of these observations; *viz.*, with an anterior separating prism to confine the grating's view to one colour region, or nearly so, of the spectrum at a time. And that again reduced to a minimum the chance of occasionally mistaking intruding lines from an overlapping order of spectrum, for those of the order intentionally in the field of view,—a source of error to which Gratings are peculiarly liable.

A ruder but more powerful source of occasionally possible error, existed in an imperfect action of the inspecting telescope, combined with the peculiarities of vision through a narrow vertical slit. For though when the focal position of the eye-piece was too far *out*, that fact was easily shown, and as it should be by a haziness in the image of a line, yet when it was too far *in*, every line in the field of view split immediately and sharply into two: and these separated further and further from each other, as the error of the focus increased. Wherefore the appearance of close and *similar* double lines had to be jealously watched whenever the observer's telescope, by passing from green to violet of the spectrum, was innately growing in focal length. On the other hand, when the definition of the atmosphere was bad, the members of a really double line would throw out fringes of haze towards each other, and conceal thereby their real duplicity, if very close. While all the time alteration of focus had to be very sparingly employed, as it was only too apt to spoil the nicety of bisection.

Something also of the highest accuracy may have been lost, in exchange for the greater speed at which the observations both were, and imperatively required to be, secured whenever the sunshine was continuous. In his authoritative little work, *Studies in Spectrum Analysis*, Mr Norman Lockyer has rightfully stigmatised the slowness of the ordinary hand and eye micrometer observation, as only enabling a careful observer "to lay down ten lines an hour." But with the peculiar method,—utilising *both* hands *and* the eye,—which I arranged for this spectroscope, I was enabled on Thursday, June 26, 1884, to lay down permanently 1865 lines in three hours.

Yet where so many opposing difficulties are concerned, I cannot perhaps do better than conform at once to the General Secretary's suggestion to give further details as to the chief apparatus, and the daily circumstances under which the three several spectra were measured.

Now these latter were thus :—

First Winchester Solar Spectrum, 1884.

Portions of Spectrum in W. N. Place.	Day of Observation.	Order of Grating's Spectrum used.	Coloured Glass Screens employed in front of Slit.	Max. Shade Temp. in Observing Room.	Water-gas in Cubic Foot of Air, outside.	Hours of Forenoon Sun-shine by Col. Knight's Recorder.	Notes at the time.
				°F.	Grains.	H. M.	
33,000–35,000	☿ June 25	1st	two blue	70·0	5·2	1 52	Between openings of clouds only.
35,000–36,500	♂ June 24	1st	1 blue + 1 red	67·0	3·6	4 15	Violet lines of 2nd order intrude.
36,000–39,700	☾ June 23	2nd	1 red	68·3	4·2	5 8	Blue lines of 3rd order intrude.
39,700–43,050	♂ June 24	2nd	None	67·0	3·6	4 15	Definition exquisite, no coloured glasses.
43,050–46,830	♅ June 12	2nd	...	68·0	4·6	4 57	
46,830–48,150	♄ June 14	2nd	...	69·7	4·3	2 46	
48,150–49,630	☾ June 16	2nd	...	62·5	3·5	1 21	
49,630–50,000	☿ June 18	2nd	...	64·5	4·0	1 52	
50,000–55,850	♅ June 19	2nd	...	66·4	4·0	3 9	Focus of Collimator thus far untouched.
55,850–58,950	♀ June 20	2nd	1 blue	67·0	4·6	5 34	Afterwards moved similarly to telescope's focal adjustment, but to half the amount only, and at frequent intervals.
58,950–60,600	♄ June 21	2nd	1 blue	66·0	4·4	3 59	
60,600–62,950	☾ June 23	2nd	1 blue	68·3	4·2	5 8	

Second Winchester Solar Spectrum, 1884.

Portions of Spectrum in W. N. Place.	Day of Observation.	Order of Grating's Spectrum used.	Coloured Glass Screens employed in front of Slit.	Max. Shade Temp. in Observing Room.	Water-gas in Cubic Foot of Air, outside.	Hours of Forenoon Sun-shine by Col. Knight's Recorder.	Notes at the time.
				° F.	Grains.	H. M.	
33,000–34,400	♀ June 27	1st	2 blue + 1 red	73·4	5·0	6 12	
34,400–43,050	♄ June 28	2nd	1 blue + 1 red	76·0	4·9	5 30	The last part of the way, 1 red glass only.
43,050–47,700	♀ June 13	2nd	None	73·0	4·8	6 4	
47,700–58,900	♅ June 26	2nd	None	72·0	3·7	6 56	A marvellous three days for nearly continuous sun-shine, *viz.*, ♅, ♀ and ♄. Says Col. KNIGHT, "It cannot last!" And it did not.
58,900–62,900	♀ June 27	2nd	1 blue	73·4	5·0	6 12	

Third Winchester Solar Spectrum, 1884.

Portions of Spectrum in W. N. Place.	Day of Observation.	Order of Grating's Spectrum used.	Coloured Glass Screens employed in front of Slit.	Max. Shade Temp. in Observing Room.	Water-gas in Cubic Foot of Air, outside.	Hours of Forenoon Sun-shine by Col. Knight's Recorder.	Notes at the time.
				° F.	Grains.	H. M.	
33,000–36,500	♅ July 3	1st	2 blue + 1 red	73·0	5·4	6 45	Little "a" in immense force.
36,000–41,750	♅ July 3	2nd	1 red	73·0	5·4	6 45	
41,750–44,650	♀ July 4	2nd	1 orange	73·5	5·2	3 40	All between clouds.
44,650–50,000	☾ July 7	2nd	1 green	68·5	4·6	3 14	
50,000–55,320	♂ July 8	2nd	1 blue	71·8	5·0	3 2	
55,320–56,000	☿ July 9	2nd	1 blue	70·5	5·6	0 18	Through clouds.
56,000–58,100	♅ July 17	2nd	1 blue	66·8	4·7	1 27	Through clouds more or less.
58,100–60,700	♀ July 18	2nd	1 blue	66·4	3·8	3 31	Through clouds more or less.
60,700–,63000	♄ July 19	2nd	1 blue	66·0	3·5	4 2	Between clouds, and with lower eye-piece.

To the above numerical particulars, the following details of focus, taken on b June 21 may be usefully added.

The Collimator being kept at a fixed focus, the telescope's focus tried on the Solar lines of the Grating's spectrum with an eye-piece magnifying 67 times, was found to be at the following successive distances in inches from its objective :—

At Solar Lines.	1st Order of Spectrum.	2nd Order of Spectrum.	3rd Order of Spectrum.
Great A	(68·55) ?	Mixture of Spectra.	Mixture of Spectra, shown by red and blue lines intermingled.
Little "a"	68·43		
B	68·39	B = 68·57	
C	68·36	C = 68·50	
D	68·31	D = 68·43	D = 68·46
E	68·34	E = 68·43	E = 68·46
F	68·39	F = 68·46	F = 68·52
F to G	68·47	F to G = 68·55	Mixture of Spectra again, red and blue lines intermingled.
G	68·59	G = 68·70	
H	(68·72) ?	Mixture of Spectra.	

These numbers show that Messrs Cooke's form of achromaticity of objectives, gives a more nearly uniform focus throughout the spectrum than is generally met with. Yet that very excellence rather conduces sometimes to the mistaking of intermingled lines of two adjacent orders of the Grating's spectra.

Such intermingling was probably less on this occasion than it often is, by reason of the employment of a large anterior prism, which never allowed a white image of the Sun to fall on the Slit, from the Heliostat's condenser lens (6 inches in diameter and 90 inches focus); but spread it out sideways as a short spectrum-coloured smear. Of very "impure" spectrum-character no doubt, yet enabling the greater mass of each individual colour to be thrown separately on the slit at will.

The Prism was of moderately good Flint glass, of 38° Refracting Angle, and with the faces enclosing that angle, measuring 5 by 5 inches. It was inserted transversely into the cone of Solar rays coming from the Heliostat lens, 65 inches before they arrived at a focus; and the large spectroscope table, carrying collimator, grating and telescope on its surface, rotated horizontally round a vertical axis under the centre of the prism; and could afterwards be adjusted slowly or definitely fixed by a grand screw motion in tangential direction at the outer end of the whole and on the floor level,—when the collimator had been placed by trial in the line of *minimum* deviation for the prism at the part of the Spectrum under observation with the Grating.

In the third Winchester Spectrum, more use was made of coloured glasses

than in the first two; with the effect of spoiling the purity and beauty of spectrum colour, but of blackening the lines, without I hope disturbing their position for differential measures such as mine.

Part VI.—Appearances and Disappearances of Terrestrial Water-Gas lines in the Solar Spectrum.

But the most powerful cause of all, for altering the very physiognomy of some districts of the spectrum, is due to the invisible vapour, or gas, of water dissolved in the lower strata of the atmosphere; and thickening or thinning certain lines, or making new ones, according to its varying amount from day to day, from season to season, and from one country to another. In the dry climate of Portugal in June, and near Noon-day, I could only see a few mediocre lines occupying the spectrum place of "little *a*" and its preliminary band—both of them due to water-gas. So likewise was it in Edinburgh during the early days of May, in the present year 1885, when the air was both cold and dry; or with a temperature of 46°, and grains of water-gas in a cubic foot of air = 2·6 only. But in Madeira, that "Ocean-flower" fed by perpetual exhalations from the warm currents around it, with a July temperature of 72°·9, and grains of water-gas = 6·49,—both those constellations of spectral water-vapour lines, even in a high Sun, were rich exceedingly in thick, black groups inimitably defined on brilliant red light, so as to form quite an inspiriting sight to have beheld once in one's life.

And at Winchester, in both June and July, I am bound to confess that the said constellations put on a most respectable appearance, under the usual impregnation of the air in that locality and at that season to the extent of 4·5 and even 5·0 grains of water-gas to the cubic foot; chiefly thickening lines already known both to exist, and to represent water vapour.

The puzzling manner however in which the thinnest class of Fraunhofer lines, if of water-gas, may either appear, or entirely disappear in the spectrum, in places where they might have been entirely unexpected by the observer,—was first and well described by Professor Josiah P. Cooke, of Cambridge, Mass., U.S., in a contribution to the American Journal of Science in November 1865. For, confining himself there, to the narrow space between the two Solar and therefore permanent and steady D lines in the Yellow,—he showed how the number of thin interstitial lines increased, just as the weight of water-gas in the cubic foot of air gradually enlarged from 0·81 to 6·57 grains.

Professor Cooke further reasoned well on the Annual Maximum of such lines occurring in the American autumn, when the weight of such transparent water-gas dissolved in the air, but not forming clouds, or interfering with the brightness of the Sun, comes also to its maximum.

Now this weight of water-gas in the air, is quite a different matter to the

usual term of "Humidity" among Meteorologists, but which is in reality "Relative Humidity" only; and means nothing for spectroscopic purposes, nor for absolute chemical composition either, unless accompanied by a statement of the temperature at the time. This may be well illustrated by the excellent annual account of New York Meteorology published by Dr DANIEL DRAPER, at the Central Park New York Observatory for 1884. For, while his annual list of monthly means of "Elastic force of Vapour" numbers (which are but another form of "Grains of water-gas in a cubic foot of air") shows a grand curve through the year, having its minimum in January, and Maximum in August or September,—agreeably with Professor COOKE's observed growth of "Aqueous lines between D^1 and D^2"—yet the New York "Relative Humidity," runs up to its terrible maximum of 96, not in August or September, but in January! On referring however to the Doctor's Temperature return for the same month, and same hour, it is found to be only 21·42° F. Wherefore the amount of water-gas in each cubic foot of air at that time could only have been 1·3 grains; under which scarcity, all thin water-gas lines would have been practically invisible.

Even at Edinburgh, in the present month of May, looking with the identical Winchester grating spectroscope—it was almost startling to find hardly anything except the one Nickel line, by contrast most pronounced in the middle of an apparently waste, empty space between the two D's; the water-gas amounting in this case to 2·6 grains *per* cubic foot of air. While at Winchester, when assisted by double that weight, I seldom looked at the D lines without seeing eleven or more finer, and evidently water-gas lines between them, besides the solar Nickel line; and some of the former were almost as strong as that.

Although therefore definite and constant lines of water-gas have only hitherto been much noticed towards the red end of the Spectrum, where they are undoubtedly strongest, and most easy to see, yet in warm, moist weather we may expect to find them elsewhere also. And there is a narrow, but positive band of them, noticed by ANGSTROM as "strong in summer," so far away as in the further Green, or beyond little b. This band too, from the interesting manner in which it has lately been independently rediscovered, and even utilised in Jamaica as a Rain indicator, has been proposed to be named "Maxwell Hall's Jamaica Rain-band."

Besides which, Spectroscopists should be warned, that as the whole violet end of the spectrum is sensibly dulled by water-vapour when in abundance, there is most probably a formation over the whole of that region of infinitely fine linelets. And though these have not yet been distinctly resolved to view by any one,—still with every increase in the power of new spectroscopes we may expect to fall across some cases of them made visible; especially if we look under the most powerful of the appropriate Meteorological conditions.

Such for instance would be those, if true, recently described in the Newspapers, as being much complained of by our army at Suakin on the Red Sea; viz., a temperature in the shade of 110°, and a depression of the Wet bulb of 4° or 5° only; which implies no less than 20 grains of water-gas to every cubic foot of air; and would present a subject of observation to any earnest spectroscopist of perfectly phenomenal attraction,—if Government would only condescend to make it possible to him, by granting commissariat facilities of transit to, and lodging at, the place.

Part VII.—Results arrived at touching true Solar Lines in the year 1884.

It is now time, however, to return to our own more immediate subject; *viz.*, the hard and fast lines of Solar origin in the Solar spectrum. Lines which every one, in every country and in all varieties of climate sees, or should see, as constant as the Sun itself. And yet some anomalies occasionally will, and do, occur, when even such lines have to be observed and tabulated by human agency. So that an important business before us now, is to ascertain by fact, whether the method here adopted, of publishing three successive and independent spectra in final juxta-position with each other, and with two previous authorities, has any real advantage in clearing up some of those otherwise doubtful, perhaps inscrutable cases, which will now and then happen among even the latest and most carefully taken observations.

Thus at 44,620 W. N. Place, or on Plate 25, a strong line, far outside any water-gas variation effect, and represented both by M. Fievez's, and the 2nd and 3rd Winchester, Spectra, is not contained in the 1st Winchester Spectrum. So that had that view alone been published by me, it might have led to time-wasting discussions on a supposed lost line of the Solar Spectrum, vanished between 1882 and 1884; when the simpler, and I believe the true, explanation is, that the omission was merely an accidental slip on my part of one line in 6000, occurring at the *first*, but not on the *two* succeeding occasions.

On Plate 43, however, we find in M. Fievez's spectrum no symptom whatever of a very strong line, also far above water-gas variation limits in that part of the spectrum (viz., 53,673 W. N. Place), although it is conspicuously and solidly recorded on each of the three Winchester spectra.

Wherefore, if the Belgian Astronomer maintains the truth of his negation of that strong line's existence when he observed in 1882; and if neither he, nor any one else can disprove that there must have been such a line there when I observed in 1884; and, without any prepossession in favour of such a thing did on three independent occasions, separated from each other by two or three weeks,—always record a nearly first class line, whose position was subsequently

ascertained to be in the very middle of a blank region of M. FIEVEZ's Solar Spectrum map,—why this is, in so far, just the kind of result that would be given either by the Krakatao volcanic explosion having caused a transmission of some new and strange gas to the upper regions of the atmosphere,—or by something still more extraordinary having happened in the Sun. And yet I do hope M. FIEVEZ will forgive me, if I am more inclined at present to attribute the ominous-looking blank in his work to the imperfections necessarily inherent in any single-drawn spectrum map (which is by its nature positive on everything, but may be mistaken on anything likewise), than to any new gas having appeared within the last two years in either the Earth's atmosphere or the Sun's surrounding.

But when we come to the question of a possible recent increase in opaque dust effects, or a general dulling of the whole Solar and Telluric spectrum,—such indications in the Winchester work, and equally in all three of its spectra, are vast and undeniable. These dust effects, however, are more easily recognised towards each *end* of the Spectrum; for there, the "continuous" light, elsewhere in blinding excess, fades away into utter darkness, and increases thereby the sensitiveness of the photometric scale.

Compared then with what I was enabled to observe of the Solar Spectrum in Portugal in the years 1877–78,—each Winchester spectrum is deficient at the Red-end by the whole of what precedes great A; and deficient at the Violet-end by all that follows little "h," including therefore those notable spectrum milestones—so grand when the air is pure and clear, viz., great H, and great K.

But the Winchester Spectrum was observed on a grating, while prisms were used at Lisbon; and some gratings are very limited in the length of spectrum they are capable of reflecting at any time. I proceeded therefore, on returning to Edinburgh last July, to arrange a prismatic Solar spectroscope very like that employed in Portugal, though furnished with a stronger preliminary condenser for the Solar rays, and armed with very transparent simple glass prisms, in place of rather dark compound ones,—so as to make up, in Edinburgh, for the want of the clearer air, and brighter Sun, of Lisbon.

With the Edinburgh arrangement then in 1884, and during many trials there in August of that year,—I could not only see the middle of the spectrum, but also as far towards the Red as great B, rather better than I used to do at Lisbon in 1877–78. But great A, further towards the Red-end, not so well; BREWSTER'S Z still further that way and always faint in the middle of the day, not at all; his great Y line and accompanying bands, by no means so well; and his great X line, with its distant companions, not in the least degree,—though they were abundantly clear at the southern station in 1877.

Hence an extra-dulling of the Red end of the spectrum in 1884 is established with much certainty.

Again, on trying in a similar manner with the Violet end—great G, and some distance beyond it, were, with the better apparatus, seen better in Edinburgh in 1884, than at Lisbon in 1878. But every trace of light died out in the Edinburgh spectrum long before arriving at great H or great K, though they were grandiose spectral existences on the earlier occasion in Lisbon.

Wherefore the whole result of this prismatic appendix to the Winchester grating observations evidently is, that the Violet end, joined testimony with the Red, in illustrating that there actually must have been just such a dulling of the Solar Spectrum in 1884, as should arise from the upper air being at that time over-charged with opaque, dusty particles—whether from the Krakatao explosion, or any other source.

Leaving that matter, however, of location of the dust's origin, to geologists to pursue further,—I will beg leave to terminate this paper with a few words on the subject of Spectrum Scales.

Part VIII.—Testimony of successive Gaseous Groups to the most practical of Natural Spectrum Scales.

In 1878 the British Association for the Advancement of Science, published in their Dublin volume, an admirably extensive exhibition (in 52 printed pages) of the numbers for a Solar Spectrum, compiled from both M. Angstrom and Professor Kirchoff, with the chemical origin of the chief lines, and the places of all, given throughout in terms of "Oscillation frequency." This being, however, in practice, only "Inverse Wave Lengths," or the "Wave-number" here employed, though in terms of a French, instead of a British, standard of of linear measure.

In their volume for 1881 (at York) the Association has further "strongly recommended" their method of "Oscillation-frequency," as against "Wave-Lengths"; and led its Members to expect a speedy publication of lists also of the lines in Chemical elemental spectra, expressed in the terms they so much approved of. They had also in 1878 promised to distribute to the Members, at the Sheffield meeting in 1879, a map of the Solar Spectrum in terms of the same "Oscillation Frequencies." This promise, however, I have just ascertained from the Secretary, they never fulfilled; and now in their volume for 1884, where the lists of metallic elemental lines are given at last, and to the noble extent of 95 pages,—the Members, and the outside world too, will be much amazed to find, that without a word of explanation or apology, the places are all expressed in terms of Wave-Lengths.

Such a breaking of its previous promises, inferences, and example, on the part of a great Association, supposed by many to have necessarily more continuity, and less vacillation in its opinions from year to year, than any

single human being—is rather disturbing to private workers in science. And I cannot but think the change to be a mistake, wherever at least Spectrum *maps* are concerned, for this amongst other reasons derived from the Winchester records.

Viz., there are divers practical cases known, where the same chemical element repeats a certain constellation group of lines of its own, at several successive places in the length of the Spectrum. And evidently, if only for recognition purposes by means of measure, it would be of advantage to every one researching these matters, that the scale of a spectrum map should be such, that each of these repetitions of a recondite natural phenomenon should be presented of the same *size*,—in whatever successive colour of the spectrum it may reappear.

Now the grandest example throughout the whole Solar Spectrum, of such a repetition-form, is without doubt set forth in those three most striking linear constellations of great A, great B, and the Alpha band; all of them now considered to be due to absorption by cold Oxygen in telluric, and super-telluric, position.

Much of the peculiar arrangement of the lines in great B and its preliminary band, has been known for a long time past, from ANGSTROM and THALEN* downwards. But that the arrangement in great A is exactly similar, even down to the doubling of every line but one, in its preliminary band,—was only discovered with the powerful assistance of one of Mr RUTHERFORD'S best gratings so lately as 1878, by Professor LANGLEY of the Allegheny Observatory, U.S.; and that a similar arrangement prevails in the Alpha band, was the very recent and neat discovery of M. CORNU in Paris, in 1883.

Whoever too has had the privilege of repeating these observations with sufficient diffraction, or dispersion, power—must have been struck with the extraordinary perfection of the series. In the preliminary bands for at least ten couples and one single line, the emplacement is exact; and in the subsequent line groups very nearly, though not quite, or simply so; for they are

* It seems by a recent publication from Upsala, that M. THALEN with prisms, saw the clear duplicity of the linelets of Great B's preliminary band much better than did M. ANGSTROM with a small grating, mounted on a theodolite stand. In fact the latter did not see them to complete identification; and in his extreme anxiety not to pass beyond the modesty of observation and the truth of nature, disputed long before he would allow his friend M. THALEN to draw these linelets double, as *he* saw them without any doubt, on the manuscript for the immortal "Normal Solar Spectrum." They were however so drawn at last by M. THALEN, and were so engraved by the lithographer; but on *his* sending a proof of his work for correction to M. ANGSTROM, then on his death-bed, the dying philosopher, in his over conscientious desire not to exaggerate what he had really seen, took a pencil and filled in therewith the narrow spaces between the double members of each linelet; the engraver imitated the granular pencil markings; and that is the origin of the shading by dots, quite anomalous in spectroscopy, to be seen now on the finally engraved and published Atlas of the Normal Solar Spectrum, in its particular plate representing that preliminary band of the great B line.

fraught with a further degree of close set lines and linelets; following, apparently, in each of the three cases, certain harmonic variations of one fundamental idea; and that not of the uniformity of an iron railing and its mere equal spaces, but with a delicate rise and fall of proportions most intensely admired by those of artistic mind. Wherefore every good observer, can hardly but regard with almost solemn awe, this surpassing and æsthetic symmetry of elemental matter, which is obeyed so perfectly by every vibrating atom of a given element, but remains at present beyond all human mathematical theory to equal or explain.

Now if we measure these groups on a Wave-length scale they give, as on my original instrumental records,—

Great A = 23·86 inches,
Great B = 18·40 inches, and
Alpha band = 14·98 inches;

or with most violent variations of size and a converging tendency, threatening compression amounting to practical extinction and invisibility in the much further blue, and violet, regions of the Spectrum. Regions too where every observer knows so well, that more map space than what the "Wave-length" can give, is so imperatively required to do simple justice to the increased number of lines that appear there, as compared with the Orange and Yellow domains.

But if we now measure the three Oxygen repetitions on a Wave-number scale (or practically the same as the Oscillation frequencies, so long advocated, but now at the last moment rejected, by the British Association), they come out thus, on the final plates herewith presented to the Royal Society, Edinburgh, viz.:—

Great A = 9·24 inches,
Great B = 9·00 inches,
Alpha band = 9·20 inches.

So that, as a natural representation, and in accord with the latest discoveries of both Solar and chemical spectra, there is not at present known any better scale than that which has been employed, for already published good physical reasons, throughout the 60 plates of this paper on "The Solar (grating and glass-lens) visual Spectrum in 1884." And these plates themselves now follow,—with their naturally expanded room for Blue, Violet and Ultra-violet, lines,—to aid quick and easy examination of their multitudinous natural features, which consist as often in the grouping of many close lines, as in the absolute place of one standing solitary by itself.

Part IX.—The Map in 60 Plates, and with an Index Plate.

INDEX TO THE WINCHESTER VISUAL SOLAR SPECTRUM IN 1884.

SPECTRUM COLOUR AT PLACE.				
COLOUR'S NAME.	ULTRA-RED.	DEEP RED.	RED.	ORANGE.
NUMBERS OF THE PLATES BEARING THAT COLOUR.	*Not visible here.*	**2** *to* **7.**	**8** *to* **13.**	**14** *to* **19.**
WAVE NUMBER PLACES INCLUDED THEREIN.	10,000...33,000.	33,000.....36,000.	36,000.....39,000.	39,000 .....42,000.
STANDARD LINES ALSO INCLUDED THEREIN.	GREAT X = 29,680. GREAT Y = 30,860. GREAT Z = 31,900.	GREAT A = 33,400. *Little* a = 35,350.	GREAT B = 36,988. GREAT C = 38,707.	*Alpha band* = 40,462.
WAVE λ PLACES SIMILARLY INCLUDED.	*2,5400...7697.*	*7697.....7055.*	*7055.....6513.*	*6513.....6048.*
STANDARD LINES IN W. λ. ANGSTROM'S NORMAL SOL. SP.	GREAT X = *8558.* GREAT Y = *8231.* GREAT Z = *7962.*	GREAT A = *7605.* *Little* a = *7285.*	GREAT B = *6967.* GREAT C = *6562.*	*Alpha band* = *6278.*

YELLOW.	CITRON.	GREEN.	GLAUCOUS.
20 *to* **25.**	**26** *to* **31.**	**32** *to* **37.**	**38** *to* **43.**
42,000.....45,000.	45,000.....48,000.	48,000.....51,000.	51,000.....54,000.
Rain band = 42,800. GREAT D = 43,108.	AURORA'S *Chief Line* = 45,550.	GREAT E = 48,205. *Little* b = 49,005.	*Little* c = 51,242. GREAT F = 52,255.
6048.....5644.	*5644.....5292.*	*5292.....4980.*	*4980.....4704.*
Rain band = *5935.* GREAT D = *5892.*	*Aurora's* *Chief Line* = *5576.*	GREAT E = *5269.* *Little b* = *5183.*	*Little* c = *4957.* GREAT F = *4861.*

				SPECTRUM COLOUR AT PLACE.
BLUE.	DEEP BLUE.	VIOLET.	ULTRA-VIOLET.	COLOUR'S NAME.
44 *to* **49.**	**50** *to* **55.**	**56** *to* **61.**	*Not visible here.*	NUMBERS OF THE PLATES BEARING THAT COLOUR.
54,000.....57,000.	57,000.....60,000.	60,000.....63,000.	63,000...100,000.	WAVE NUMBER PLACES INCLUDED THEREIN.
Little d = 56,522.	*Little* e = 57,675. *Little* f = 57,954. GREAT G = 58,967.	*Little g* = 60,100. *Little h* = 61,933.	GREAT H = 64,012. GREAT K = 64,582.	STANDARD LINES ALSO INCLUDED THEREIN.
4704.....4456.	*4456.....4233.*	*4233.....4032.*	*4032.....2540.*	WAVE λ PLACES SIMILARLY INCLUDED.
Little d = *4493.*	*Little* e = *4404.* *Little* f = *4383.* GREAT G = *4307.*	*Little g* = *4226.* *Little h* = *4101.*	GREAT H = *3968.* GREAT K = *3933.*	STANDARD LINES IN W. λ. ANGSTROM'S NORM. SOL. SP.

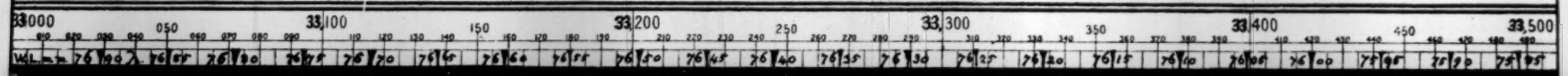
W. & A. K. Johnston, Edinburgh & London.

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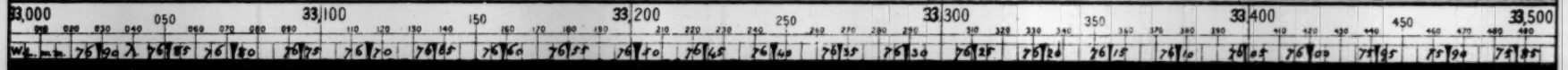
THE VISUAL SOLAR SPECTRUM IN 1884

illustrated by three separate Solar Spectra independently observed at Winchester in June and July, with a Rowland's Grating Spectroscope, by C. Piazzi Smyth, F.R.S.E.

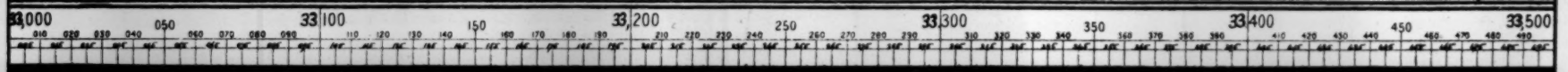
two references to older Solar Spectra by earlier observers, being prefixed: and all of them reduced to a uniform Scale of Number of Waves of Light per British inch



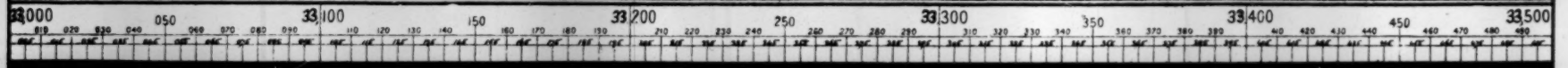
KIRCHHOFF'S SOLAR SPECTRUM, with its Metallic coincidences and Air-line non-coincidences. — *magnified laterally to suit this Scale. 1868.*



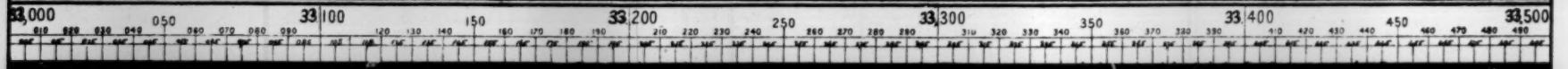
Deep Red. These Lines first discovered by Prof. Langley, Allegheny Obt. U.S. in 1878. M FIEVEZ' SOLAR SPECTRUM 1882. GREAT A. *Deep Red.*



Deep Red. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25. 1884. ⅓ *-size nearly of original Record. Long Collimator.* *Deep Red.*



Deep Red. SECOND WINCHESTER SOLAR SPECTRUM: June 13 and 26 to 30. 1884. ⅓ *-size nearly of original Record. Long Collimator.* *Deep Red.*



Deep Red. THIRD WINCHESTER SOLAR SPECTRUM. July 3 to July 19. 1884. ⅓ *size nearly of original Record. Short Collimator* *Deep Red.*

GENERAL RULES FOR THE METHOD OF REPRESENTATION ADOPTED IN THE ABOVE SPECTRA

① A Vertical line always stands for a veritable, seen and measured Spectroscopic line or image of the Slit, and for nothing else under the Sun.
② Lines in any other direction than vertical, whether horizontal or slanting at any angle and from either side, are to be interpreted as nebulous shade only in vertical bars or bands at the place
③ Greater or less height or depth, either of lines or of shaded bands, is intended to typify greater or less intensity of darkness and visibility of such lines or bands
④ Cones of shade arranged on a vertical central axis, indicate nebulous bands shaded off towards either side very gradually and delicately.

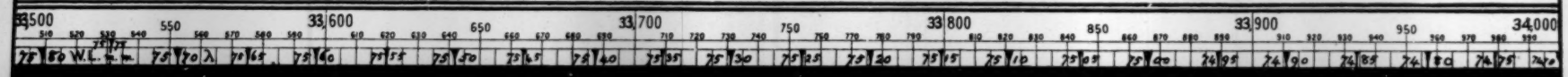
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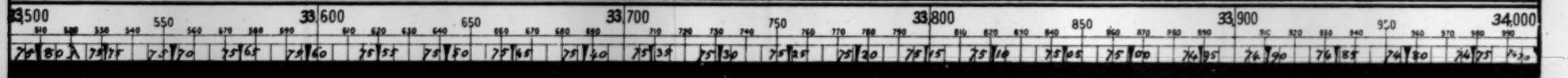
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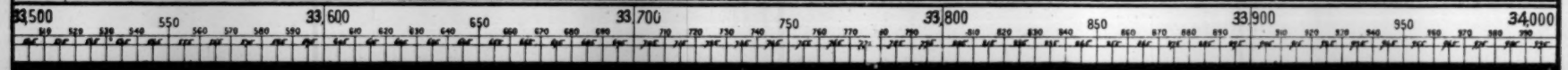
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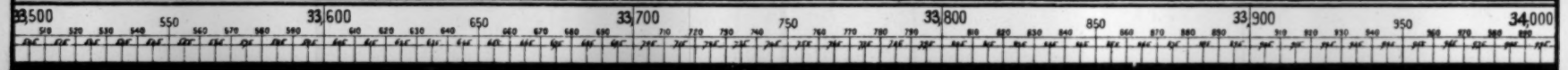
KIRCHHOFF'S SOLAR SPECTRUM with its Metallic coincidences and Air-line non-coincidences.—*magnified laterally to suit this Scale. 1868.*



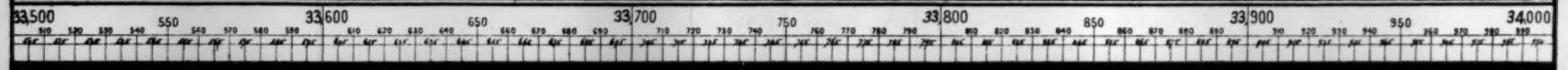
Deep Red. M. FIEVEZ SOLAR SPECTRUM 1882. *Deep-Red and Red.*



Deep Red. FIRST WINCHESTER SOLAR SPECTRUM. June 12 to June 25. 1884. *½-size nearly of original Record.—Long Collimator.* *Deep-Red and Red.*



Deep Red. SECOND WINCHESTER SOLAR SPECTRUM. June 13 and 26 to 30 1884. *½-size nearly of original Record.—Long Collimator.* *Deep-Red and Red.*



Deep-Red. THIRD WINCHESTER SOLAR SPECTRUM. July 3 to July 19, 1884. *½-size nearly of original Record.—Short Collimator.* *Deep-Red and Red.*

GENERAL RULES FOR THE METHOD OF REPRESENTATION ADOPTED IN THE ABOVE SPECTRA.

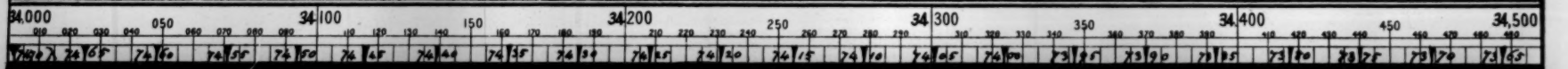
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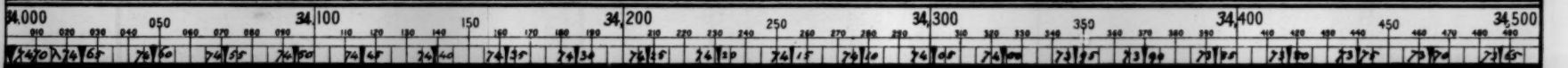
THE VISUAL SOLAR SPECTRUM IN 1884

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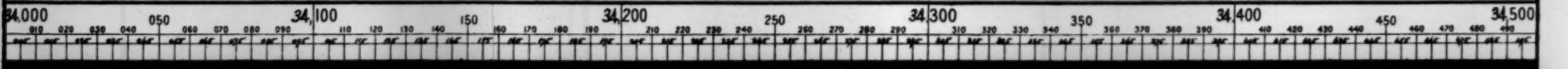
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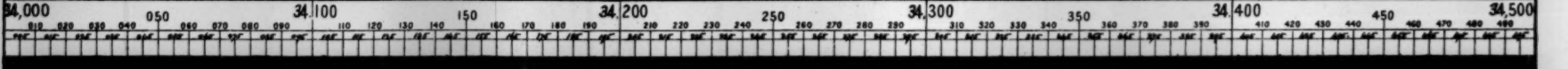
Deep-Red and Red. M FIEVEZ SOLAR SPECTRUM 1882. *Red.*



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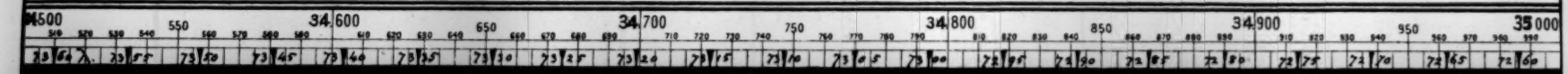
Photo-Lithographed by W. & A. K. Johnston, Edinburgh & London.

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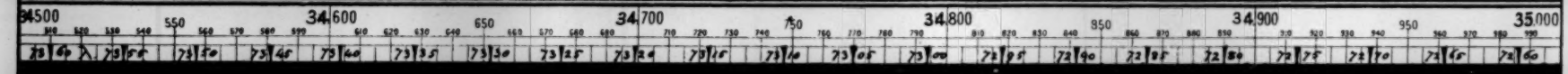
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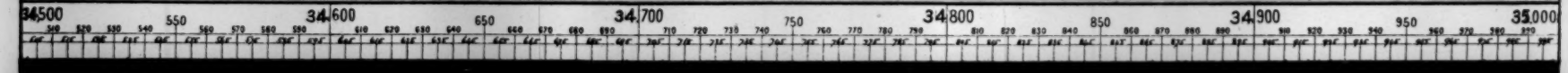
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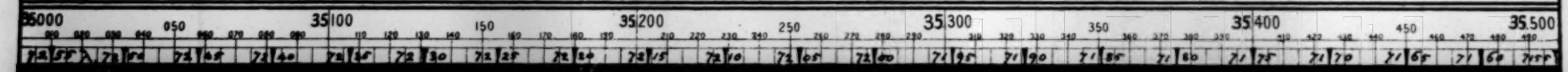
Photo-Lithograph. W. & A.K. Johnston, Edinburgh & London.

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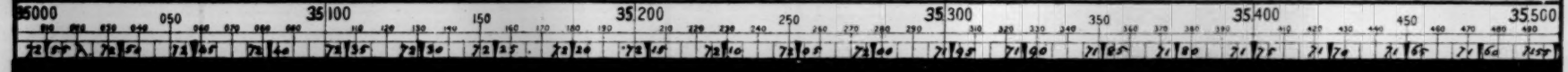
THE VISUAL SOLAR SPECTRUM IN 1884

6

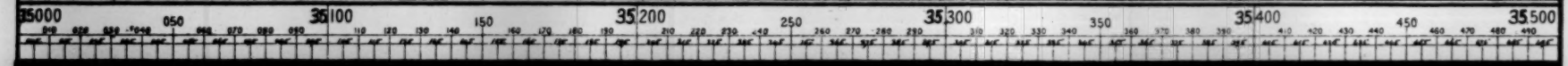
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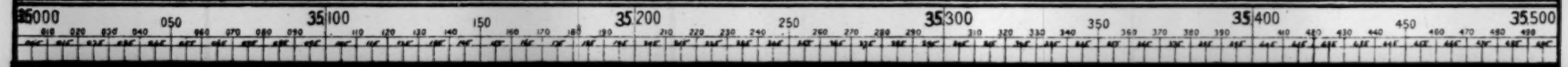
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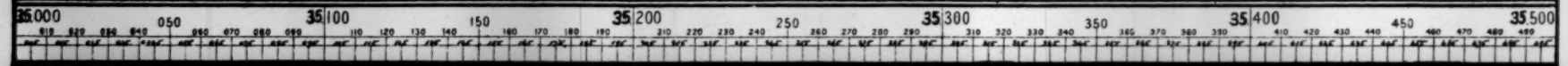
Red. M FIEVEZ SOLAR SPECTRUM 1882. Red.



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GENERAL RULES FOR THE METHOD OF REPRESENTATION ADOPTED IN THE ABOVE SPECTRA

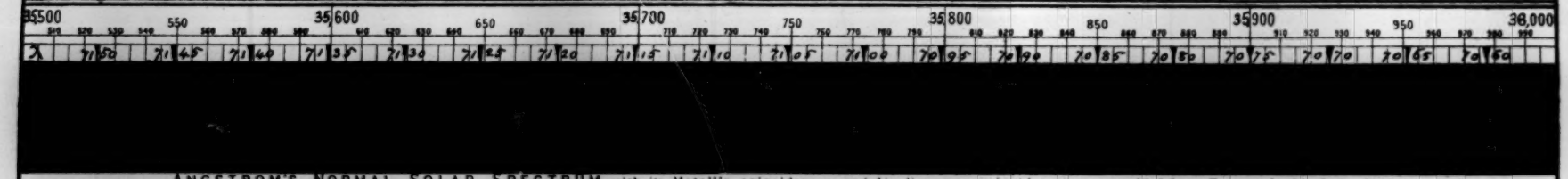
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Photo-Lithographed by W. & A.K. Johnston, Edinburgh & London.

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THE VISUAL SOLAR SPECTRUM IN 1884.

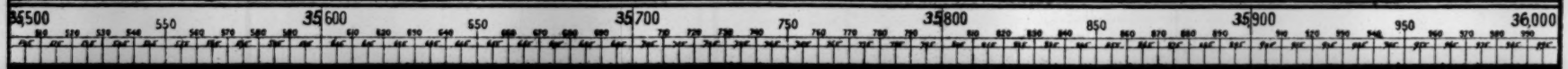
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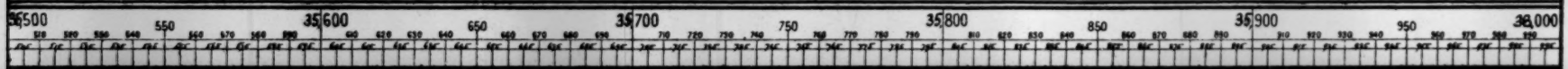
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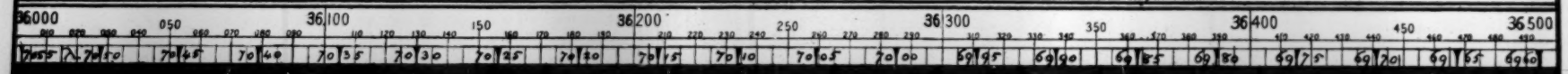
Photo-Lithograph. W. & A. K. Johnston Edinburgh & London.

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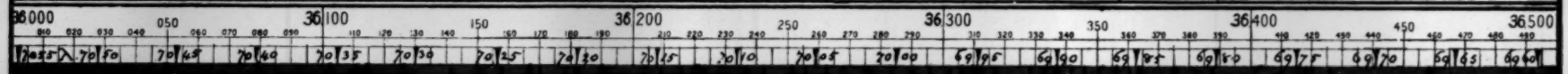
THE VISUAL SOLAR SPECTRUM IN 1884.

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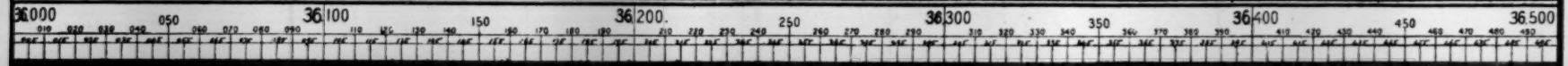
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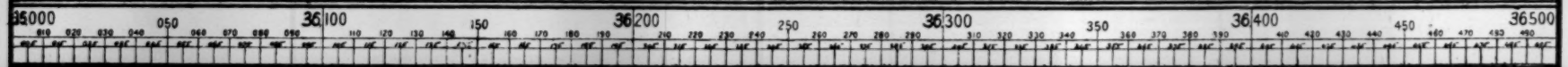
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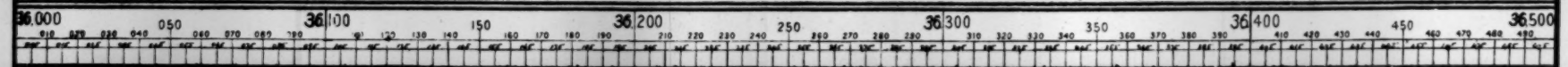
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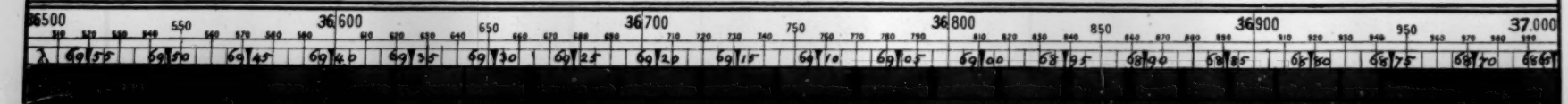
Photo-Lithograph. W. & A.K. Johnston, Edinburgh & London.

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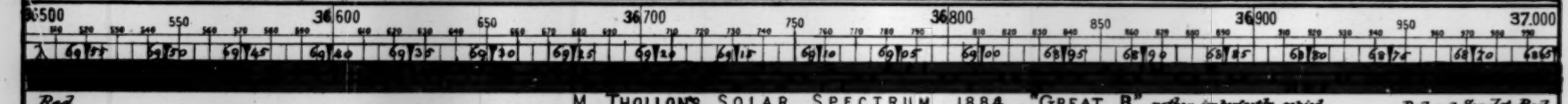
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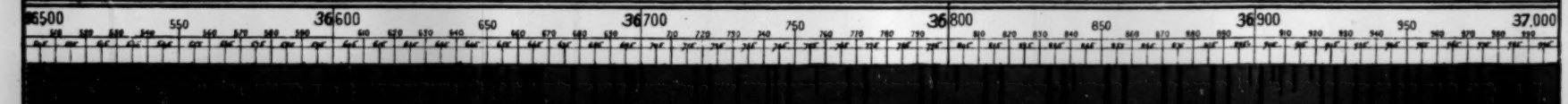
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Red. M. THOLLON'S SOLAR SPECTRUM 1884. "GREAT B", *rather imperfectly copied.* *Red and Scarlet-Red.*



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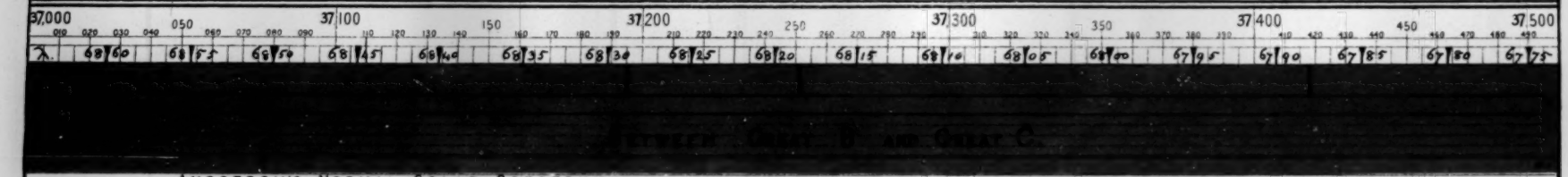
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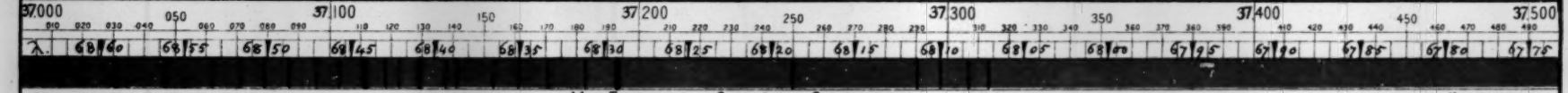
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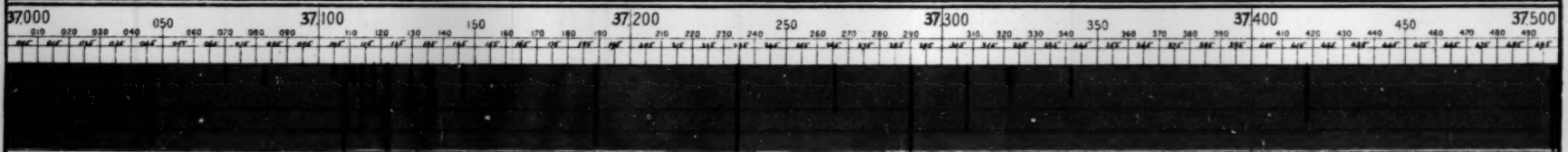
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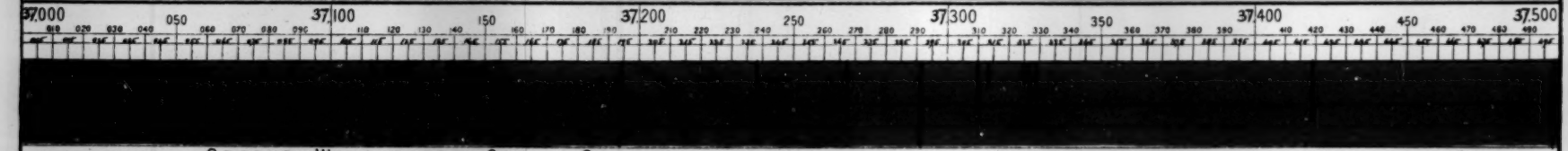
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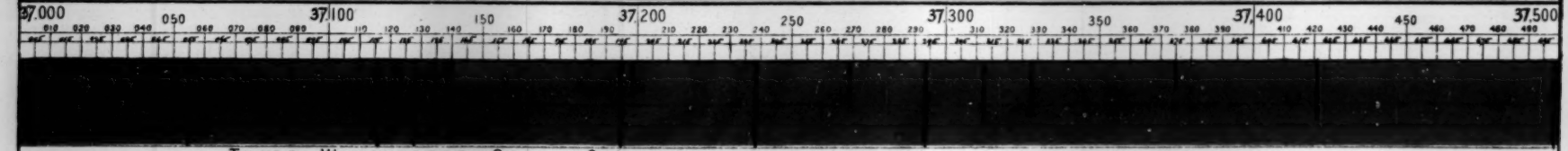
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Red and Scarlet-Red. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25. 1884. ⅓-size nearly of original Record. *Long Collimator.* *Scarlet-Red.*



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Red and Scarlet-Red. THIRD WINCHESTER SOLAR SPECTRUM: July 3 to July 19. 1884. ⅓-size nearly of original Record. *Short Collimator.* *Scarlet-Red.*

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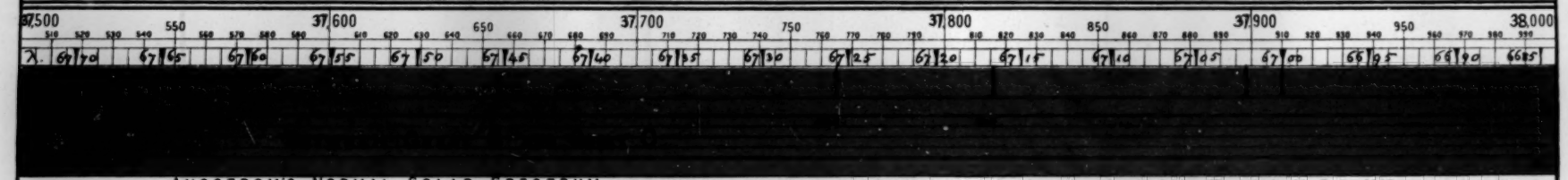
Photo-Lithographed by W. & A. K. Johnston, Edinburgh & London.

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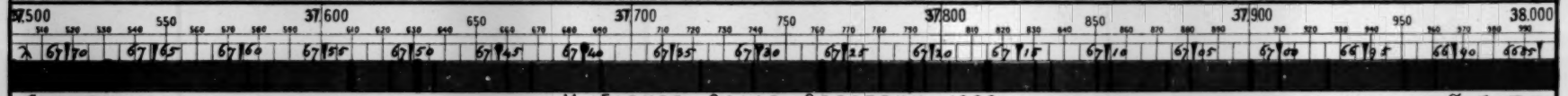
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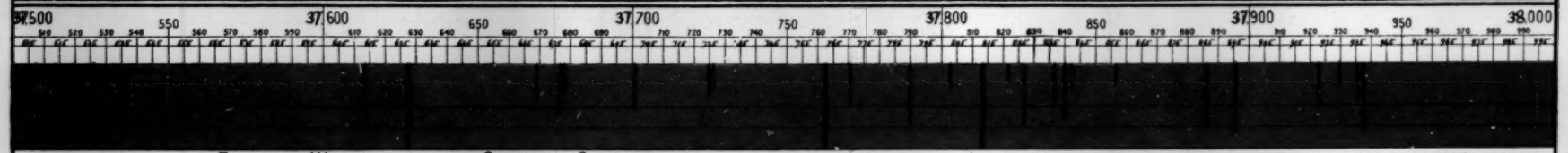
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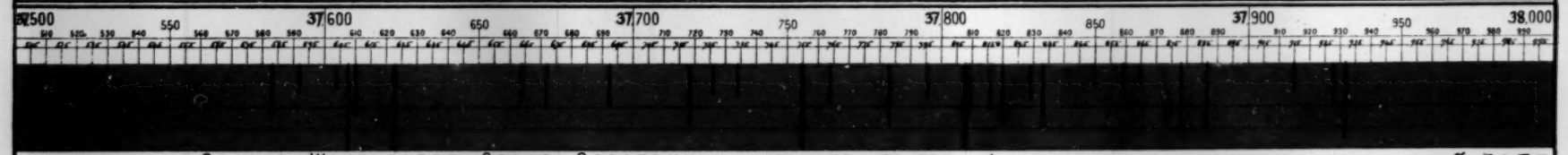
ANGSTROM'S NORMAL SOLAR SPECTRUM, with its Metallic coincidences and Air-line non-coincidences. — *magnified laterally to suit this Scale. 1868.*



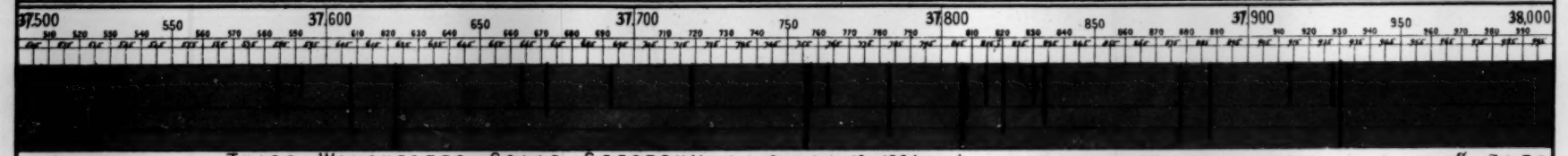
Scarlet-Red. M. FIEVEZ SOLAR SPECTRUM 1882. *Scarlet-Red.*



Scarlet-Red. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25. 1884. *⅓-size nearly of original Record. Long Collimator.* *Scarlet-Red.*



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Scarlet-Red. THIRD WINCHESTER SOLAR SPECTRUM: July 3 to July 19, 1884. *⅓-size nearly of original Record. Short Collimator.* *Scarlet-Red.*

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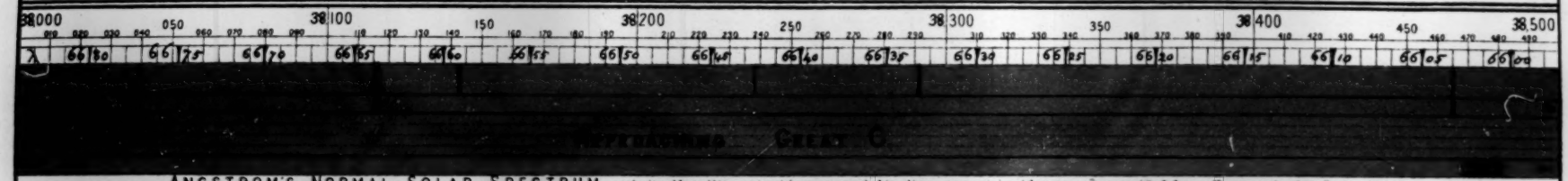
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THE VISUAL SOLAR SPECTRUM IN 1884.

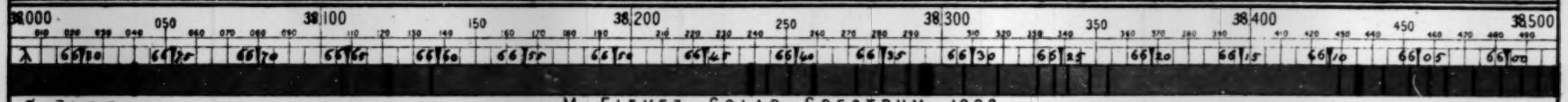
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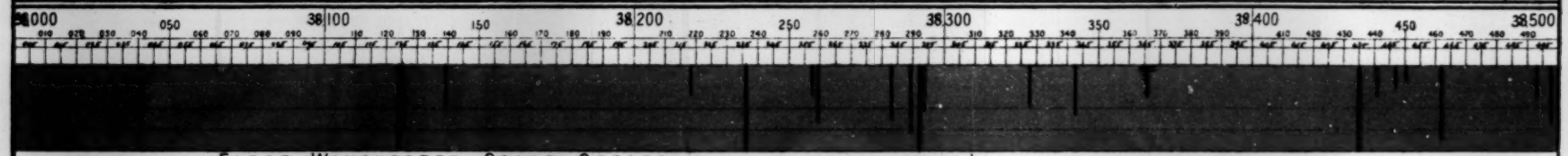
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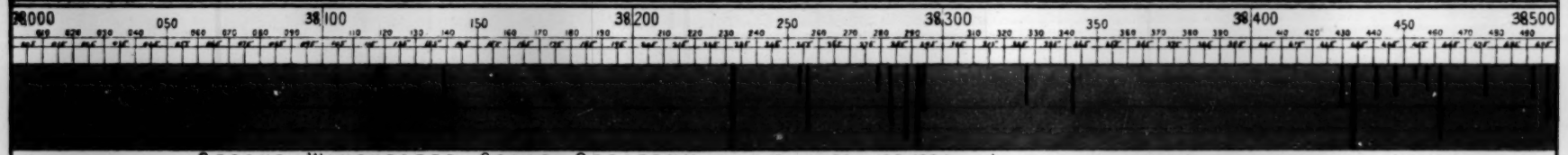
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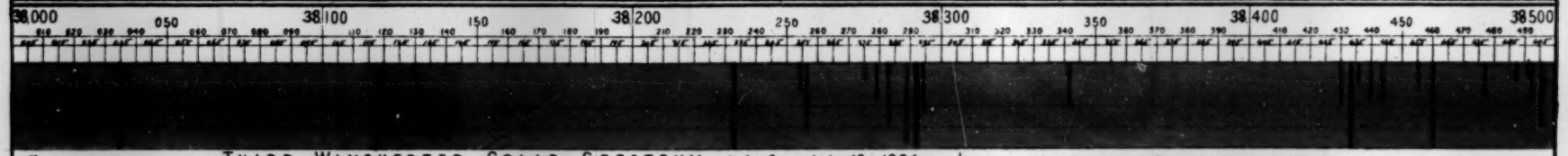
Scarlet Red. M FIEVEZ SOLAR SPECTRUM 1882. *Scarlet-Red and Orange-Red.*



Scarlet-Red. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25. 1884. $\frac{1}{3}$-*size nearly of original Record. Long Collimator.* *Scarlet-Red & Orange-Red.*



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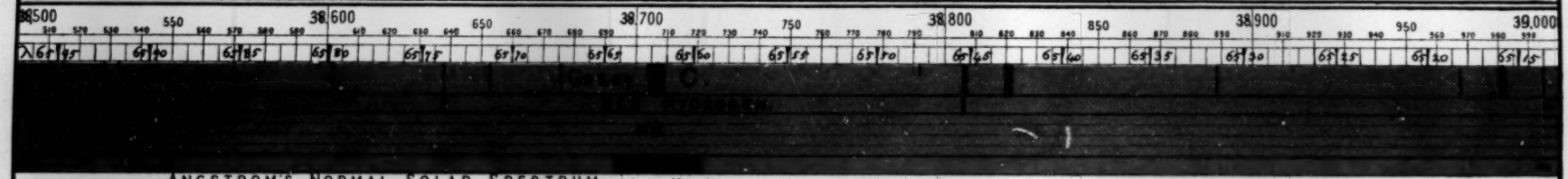
Photo-Lithograph. W. & A.K. Johnston, Edinburgh & London.

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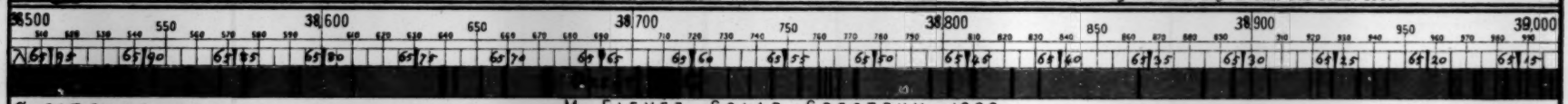
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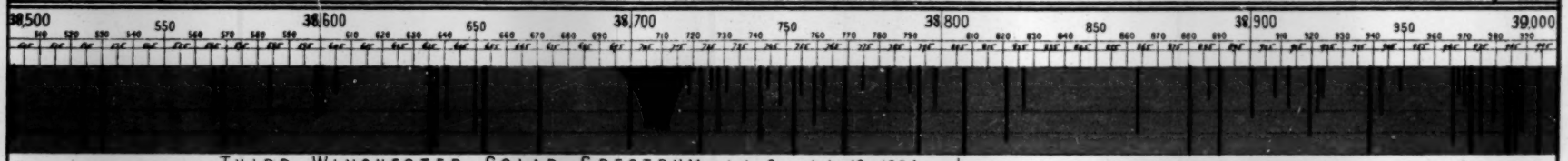
Scarlet-Red and Orange-Red. M FIEVEZ SOLAR SPECTRUM 1882. *Orange-Red.*



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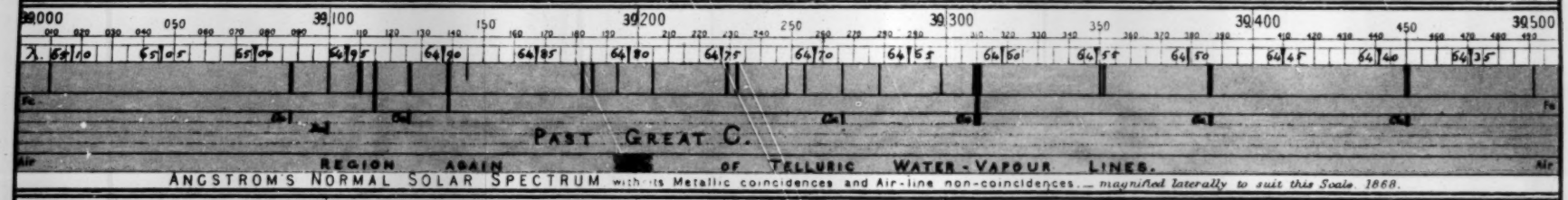
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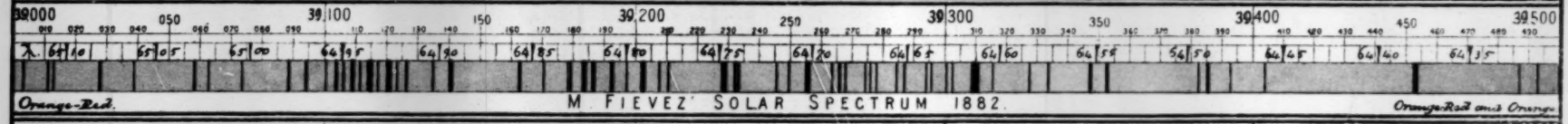
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THE VISUAL SOLAR SPECTRUM IN 1884

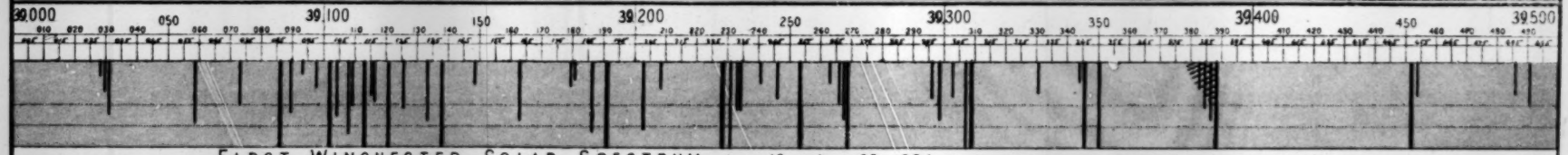
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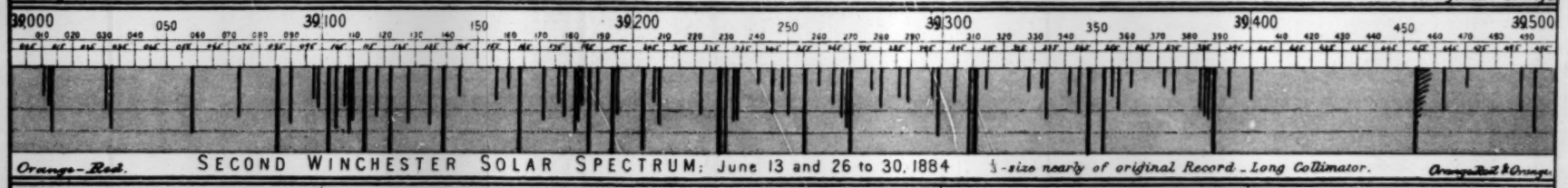
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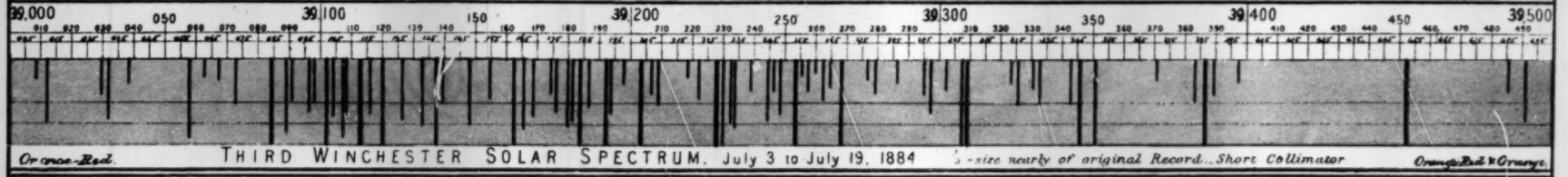
Orange-Red. M. FIEVEZ' SOLAR SPECTRUM 1882. Orange-Red and Orange.



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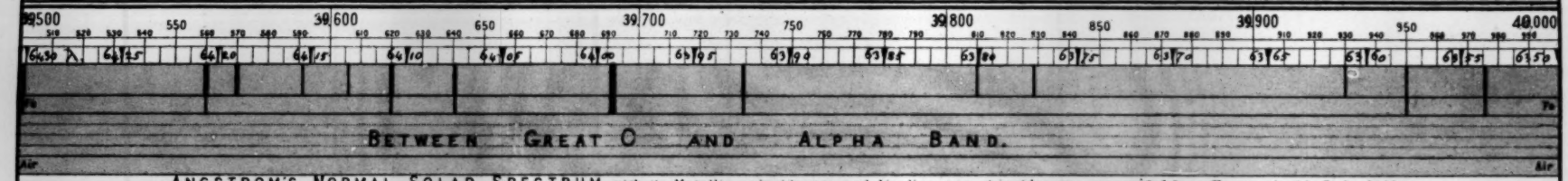
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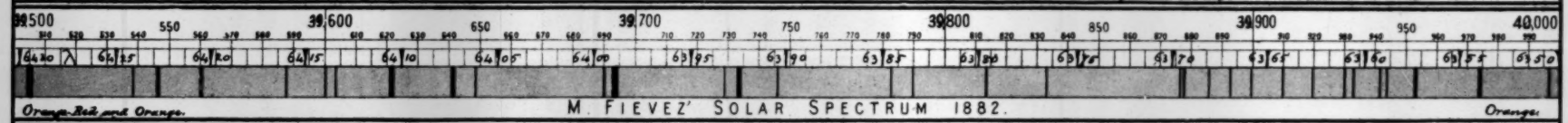
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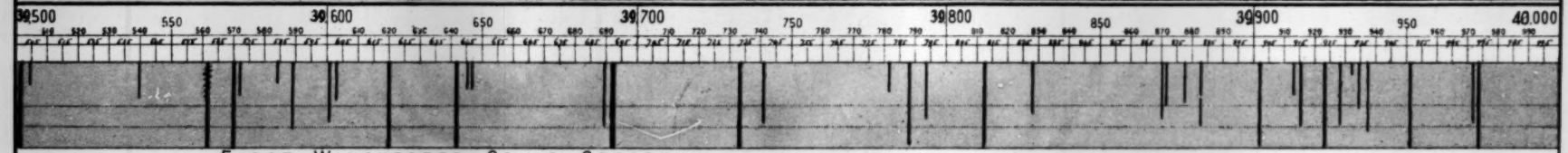
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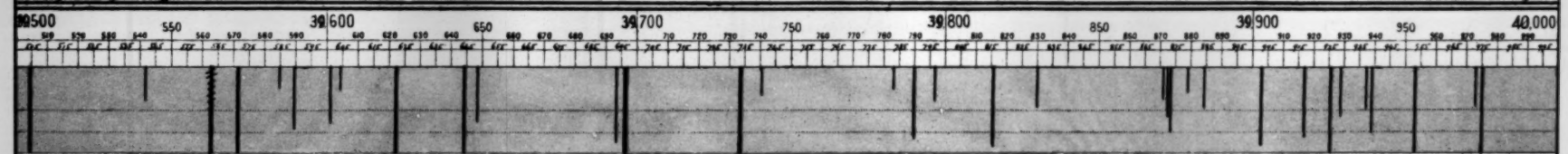
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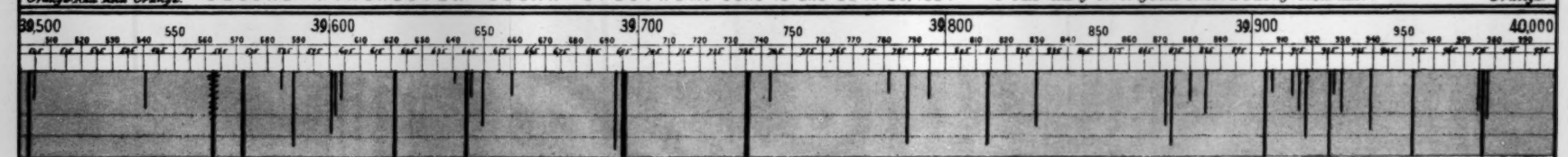
Orange-Red and Orange. M. FIEVEZ' SOLAR SPECTRUM 1882. *Orange.*



Orange-Red and Orange. FIRST WINCHESTER SOLAR SPECTRUM, June 12 to June 25 1884. *⅓-size nearly of original Record.—Long Collimator.* *Orange.*



Orange-Red and Orange. SECOND WINCHESTER SOLAR SPECTRUM; June 13 and 26 to 30, 1884 *⅓-size nearly of original Record.—Long Collimator.* *Orange.*



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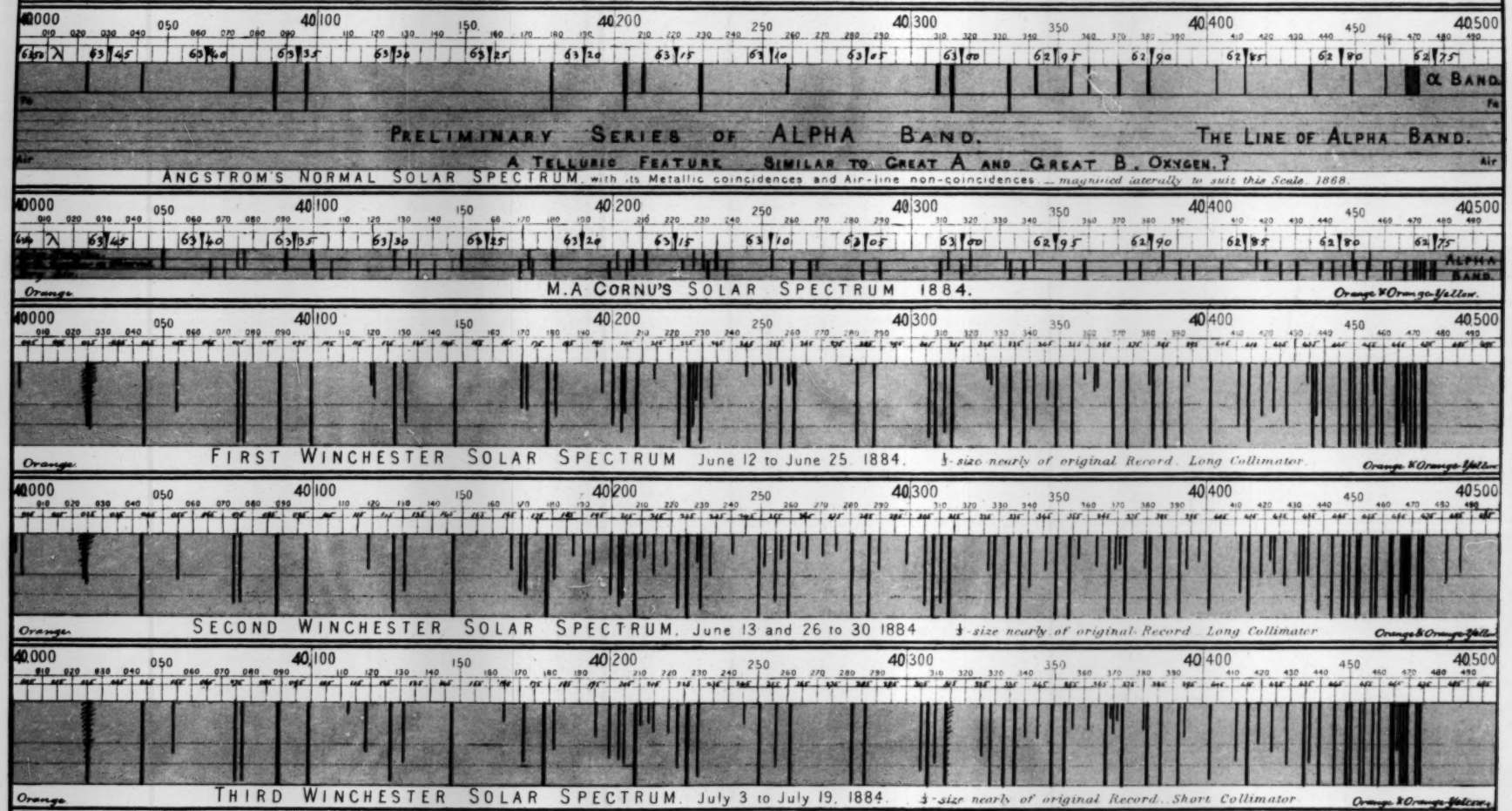
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Photo-Lithographed by W. & A. K. Johnston's Process at Edinburgh.

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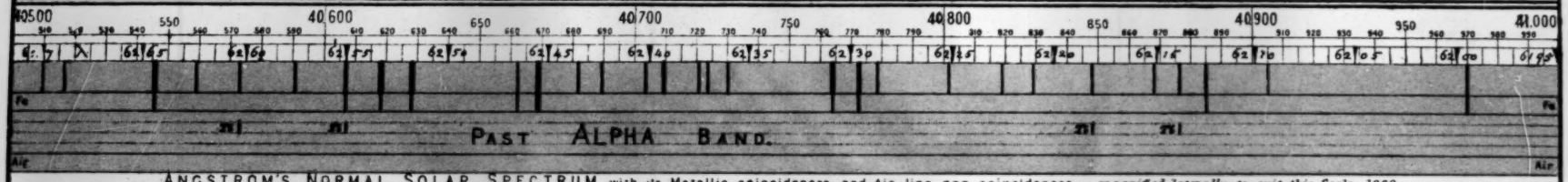
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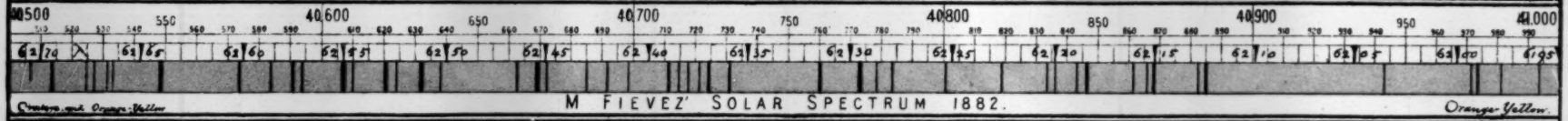
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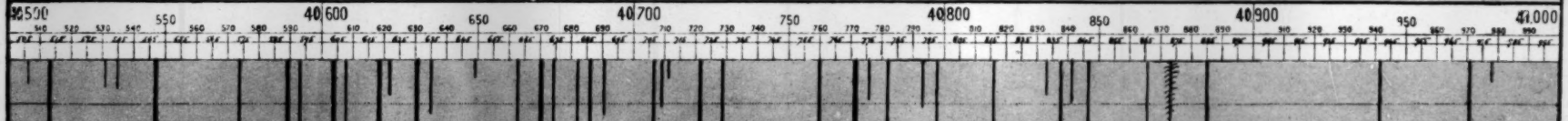
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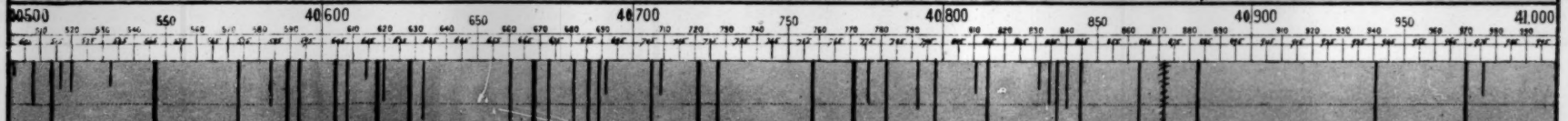
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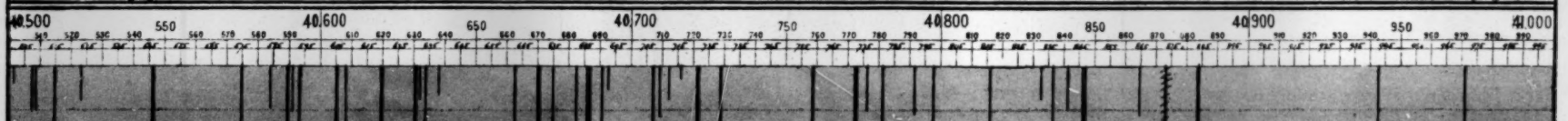
Orange and Orange-Yellow. M FIEVEZ' SOLAR SPECTRUM 1882. *Orange-Yellow.*



Orange and Orange-Yellow. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25. 1884. *⅓-size nearly of original Record. — Long Collimator.* *Orange-Yellow.*



Orange and Orange-Yellow. SECOND WINCHESTER SOLAR SPECTRUM: June 13 and 26 to 30. 1884 *⅓-size nearly of original Record. — Long Collimator.* *Orange-Yellow.*



Orange and Orange-Yellow. THIRD WINCHESTER SOLAR SPECTRUM: July 3 to July 19. 1884 *⅓-size nearly of original Record... Short Collimator* *Orange-Yellow.*

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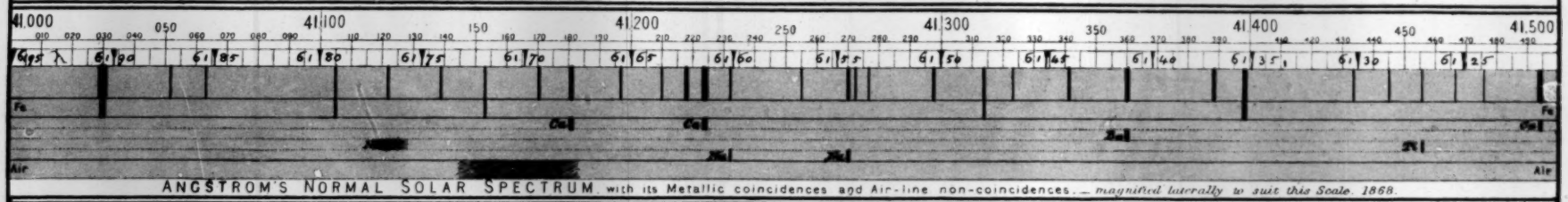
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Photo-Lithograph. W. & A. K. Johnston, Edinburgh & London.

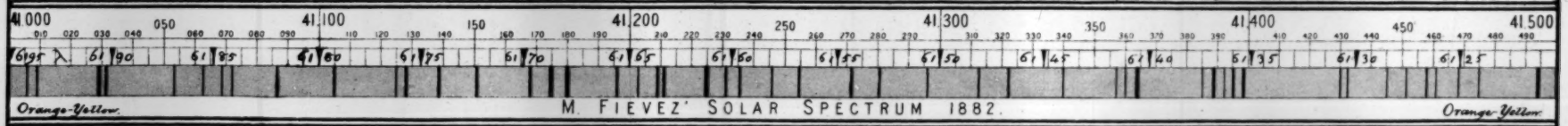
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THE VISUAL SOLAR SPECTRUM IN 1884.

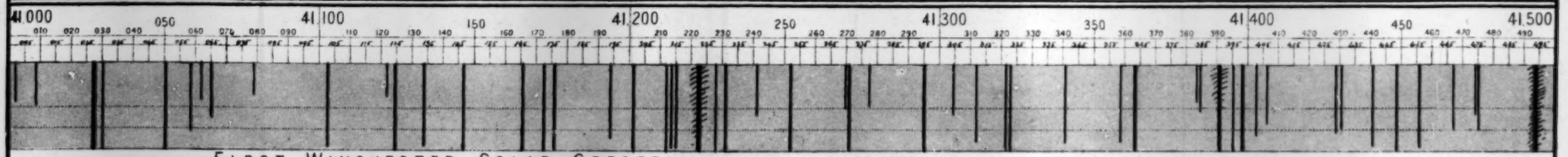
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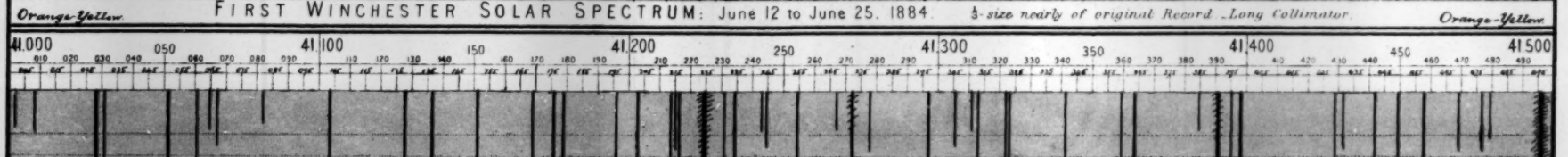
ANGSTROM'S NORMAL SOLAR SPECTRUM with its Metallic coincidences and Air-line non-coincidences. — *magnified laterally to suit this Scale. 1868.*



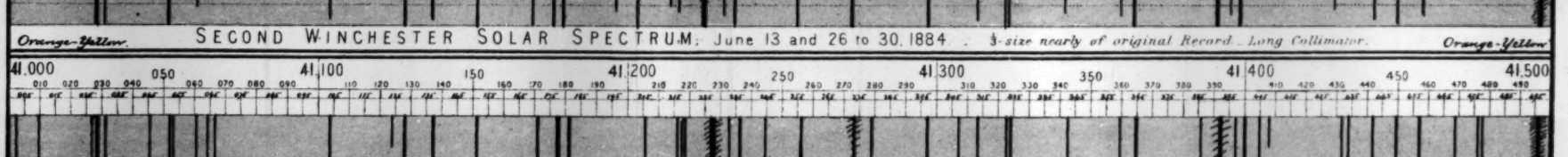
Orange-Yellow. M. FIEVEZ' SOLAR SPECTRUM 1882. *Orange-Yellow.*



Orange-Yellow. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25. 1884. *⅓-size nearly of original Record. Long Collimator.* *Orange-Yellow.*



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Orange-Yellow. THIRD WINCHESTER SOLAR SPECTRUM July 3 to July 19. 1884. *⅓-size nearly of original Record. Short Collimator* *Orange-Yellow.*

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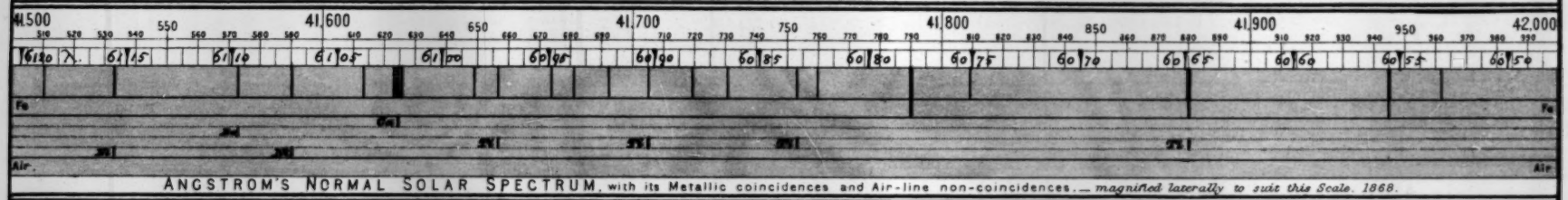
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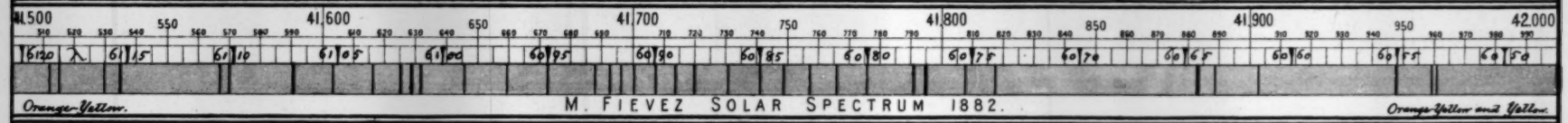
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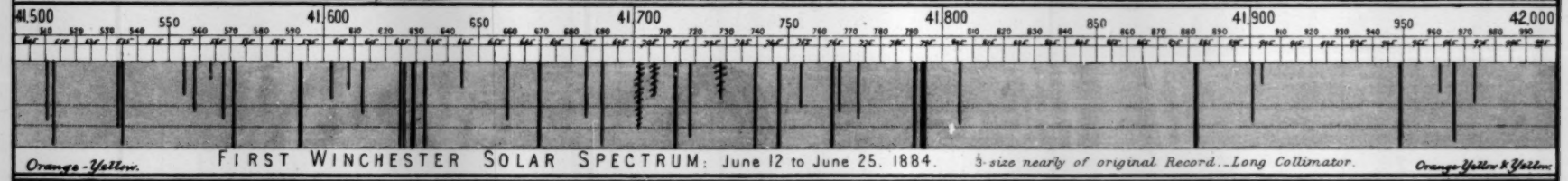
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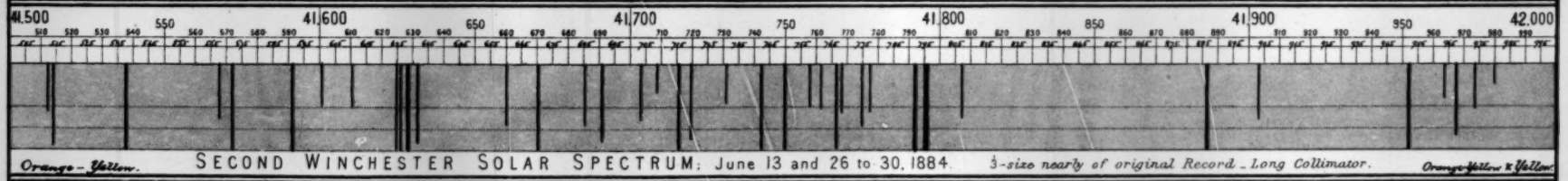
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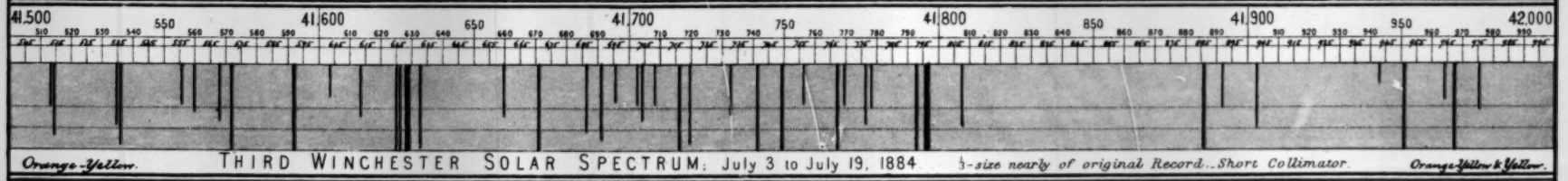
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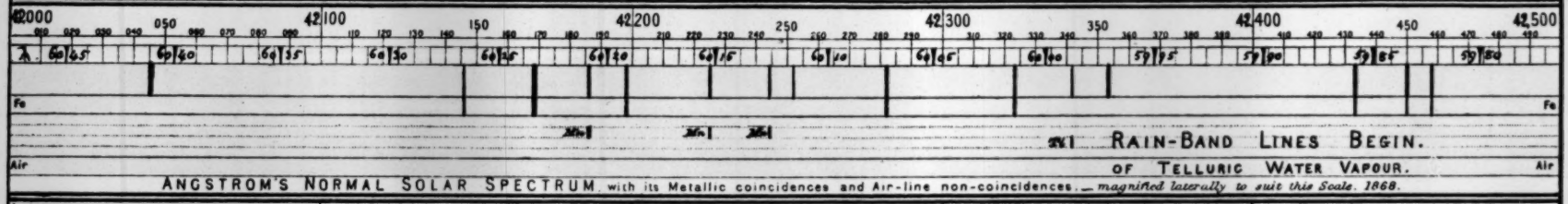
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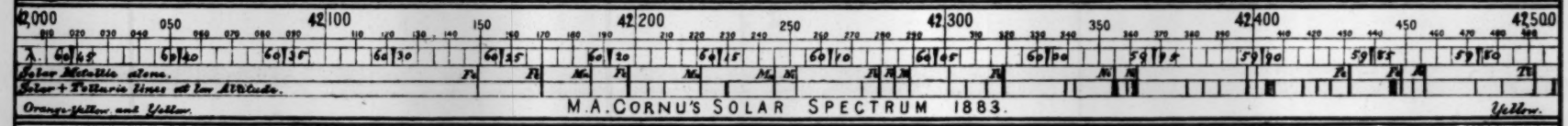
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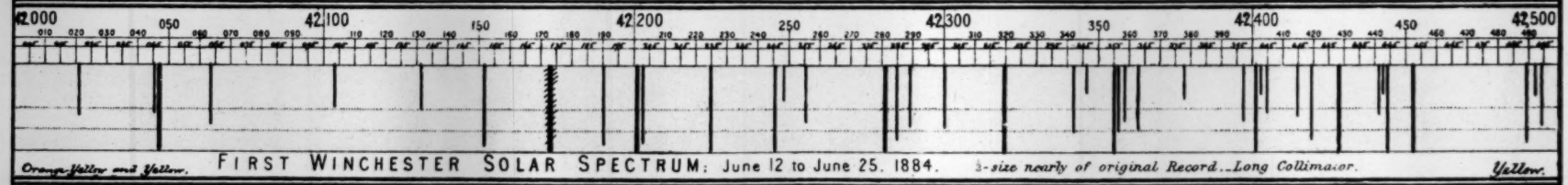
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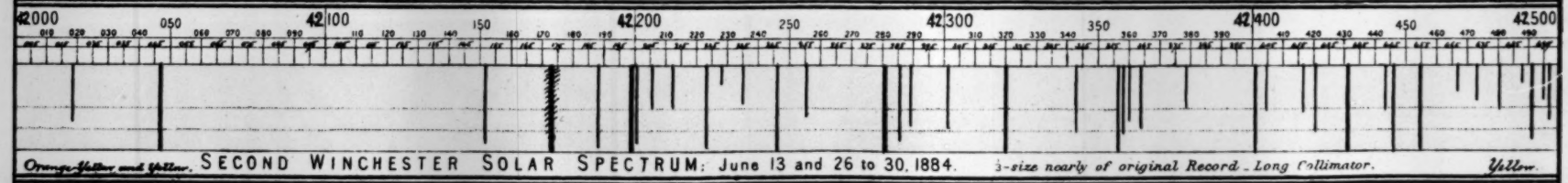
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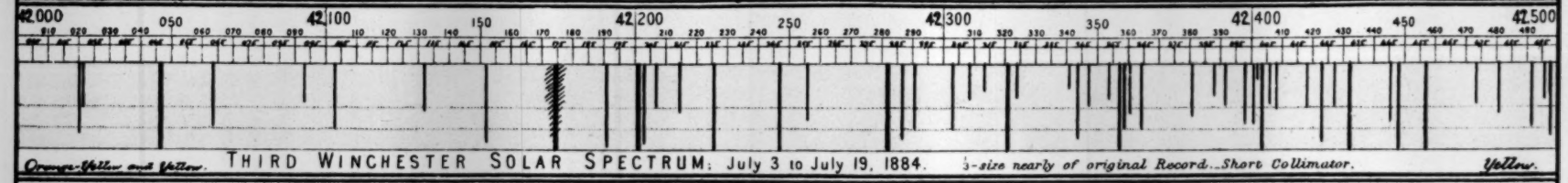
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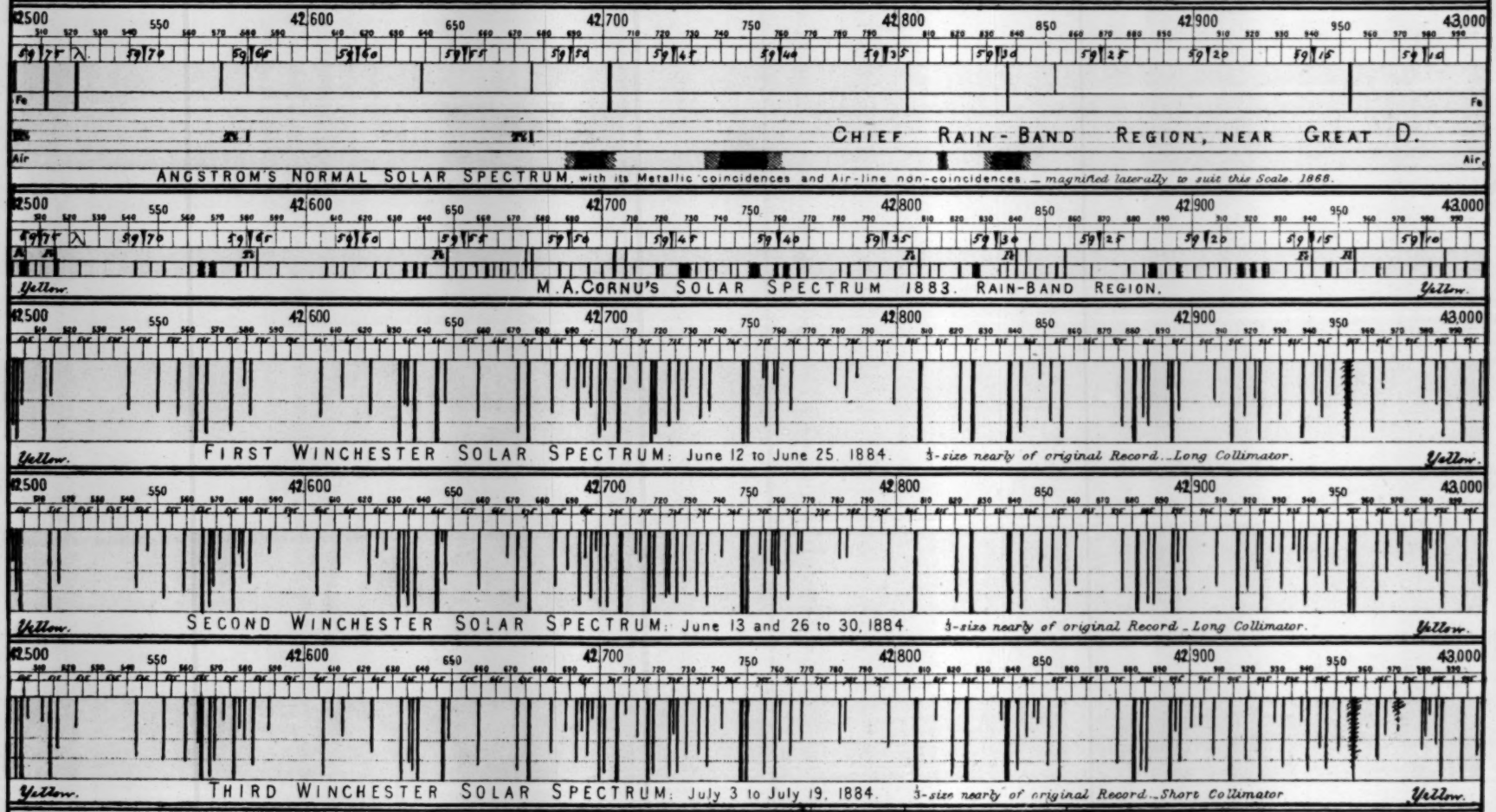
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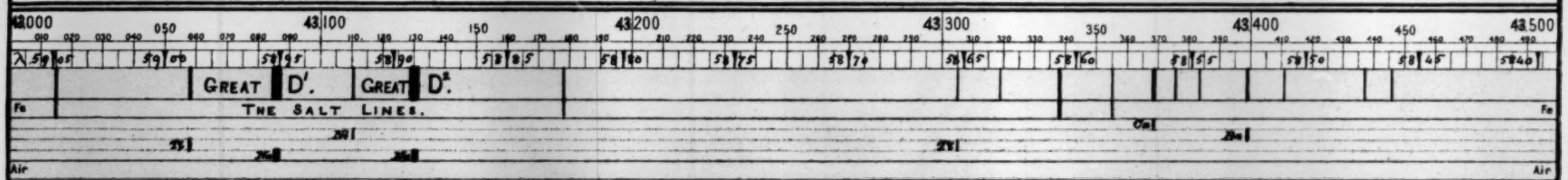
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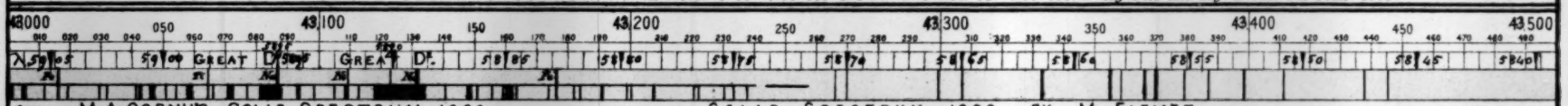
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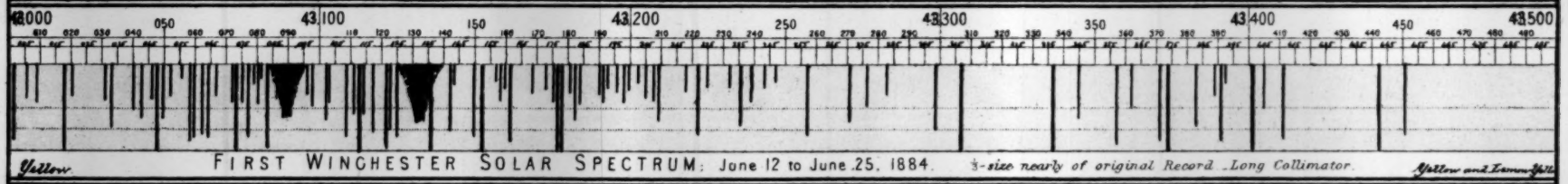
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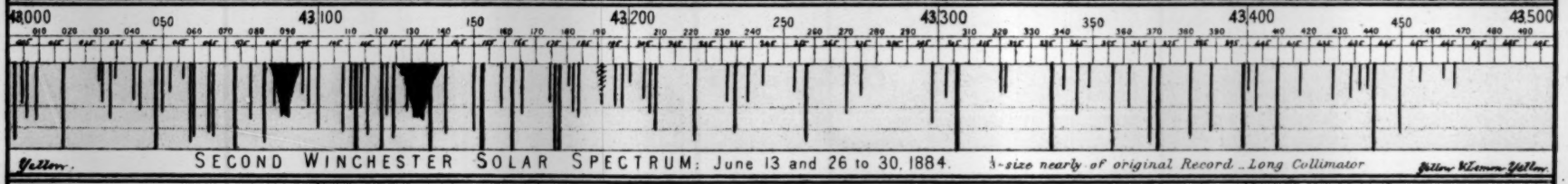
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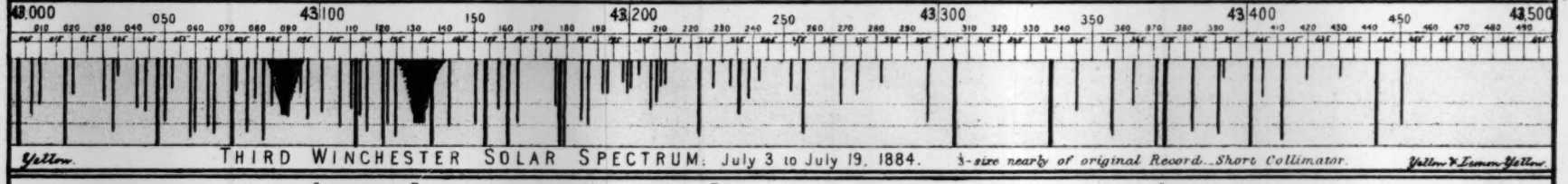
Yellow. M.A.CORNU'S SOLAR SPECTRUM 1883. —— SOLAR SPECTRUM 1882, BY M. FIEVEZ. *Yellow and Lemon-Yellow.*



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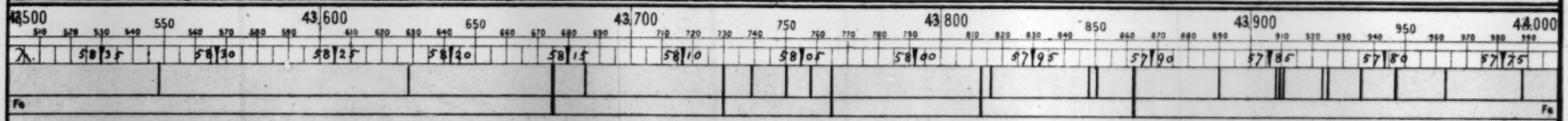
Typo-Lithograph W. & A.K. Johnston, Edinburgh & London.

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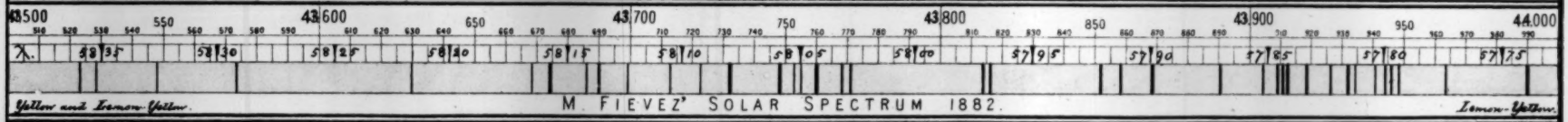
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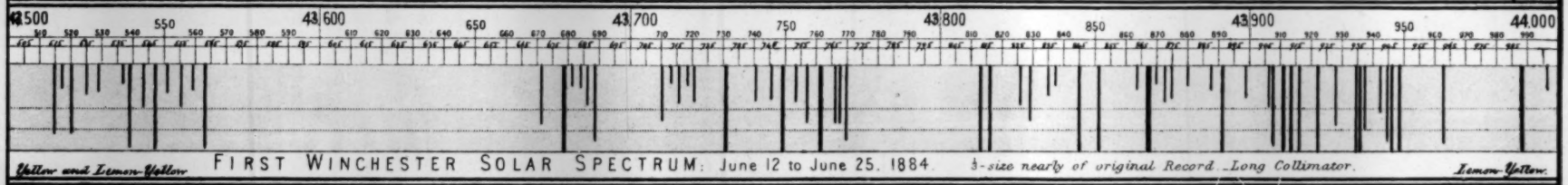
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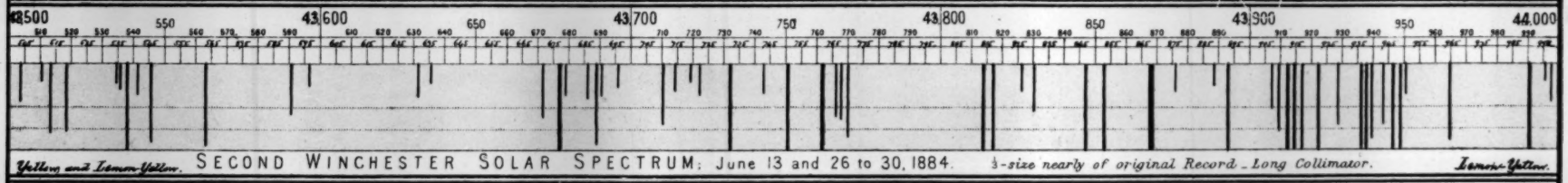
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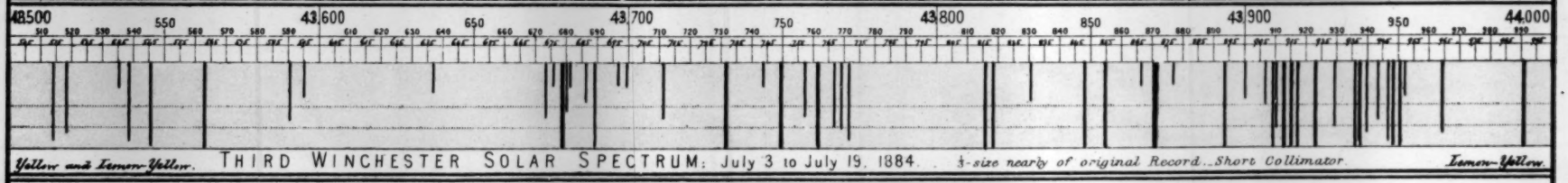


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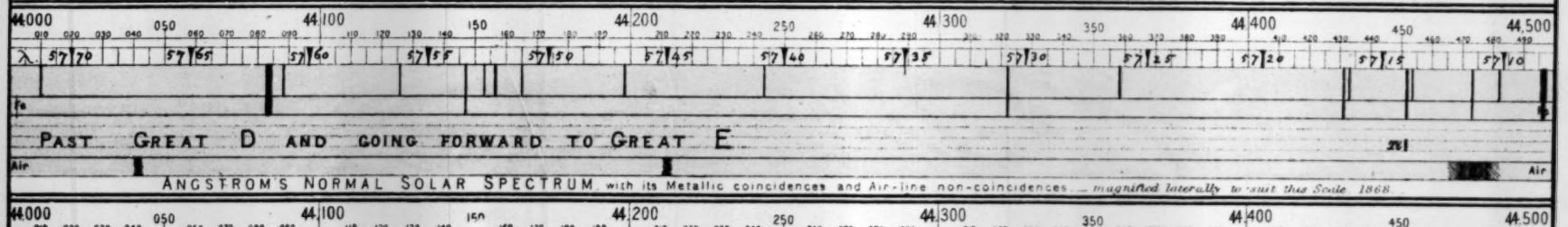
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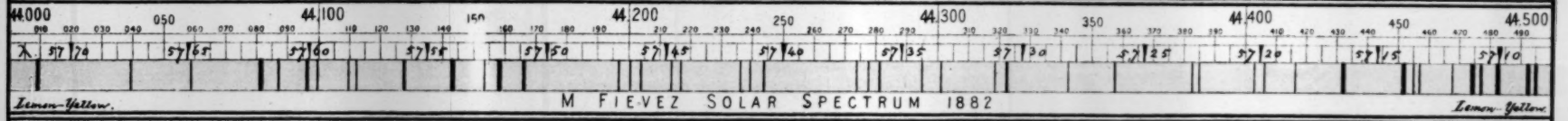
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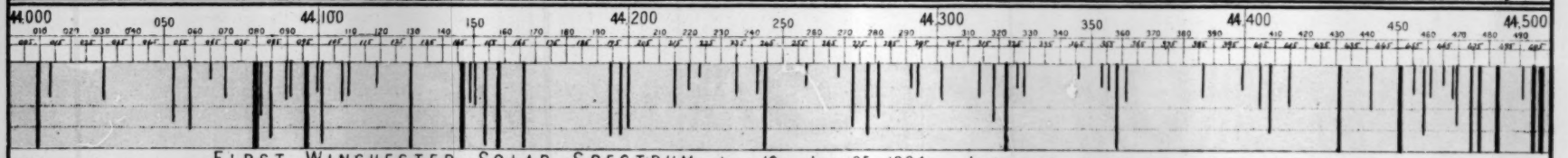
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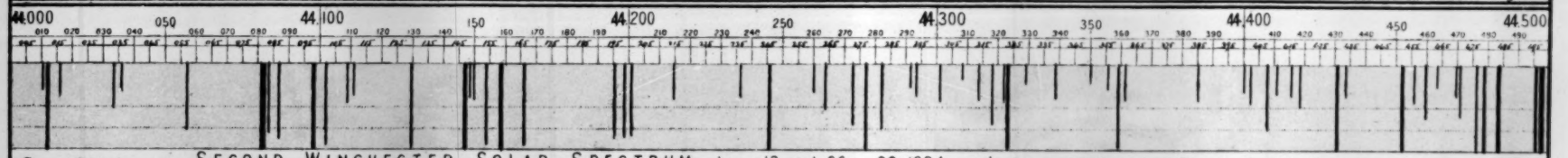
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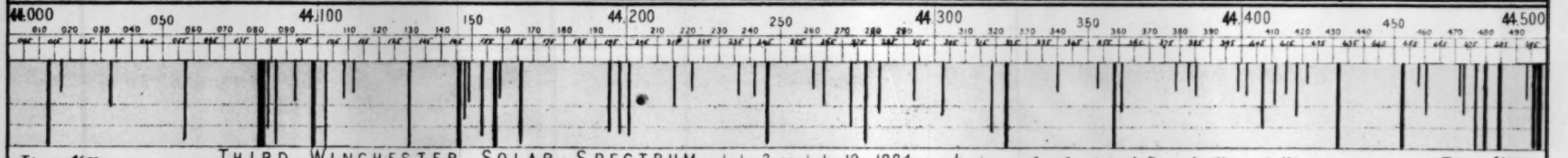
M. FIEVEZ SOLAR SPECTRUM 1882



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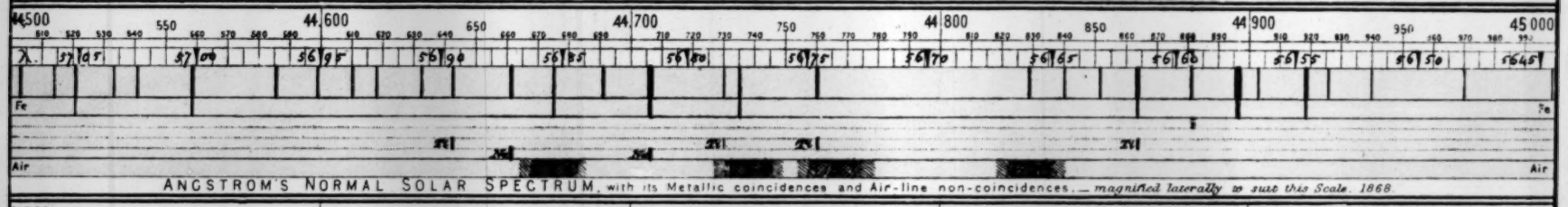
Photo-Lithograph. W. & A. K. Johnston, Edinburgh & London.

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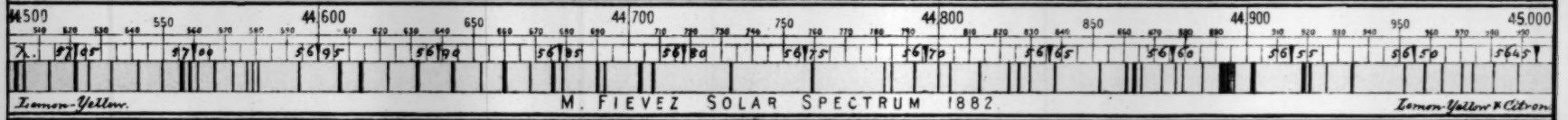
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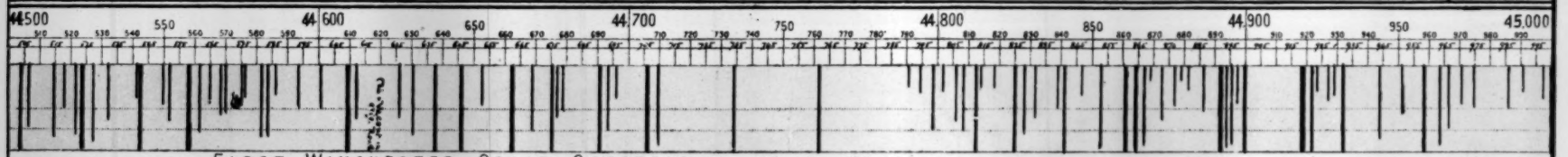
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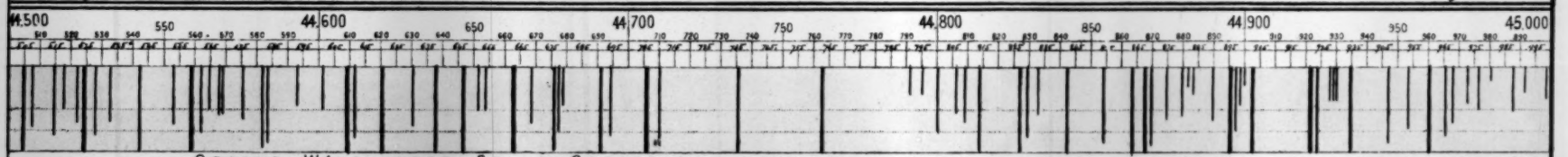
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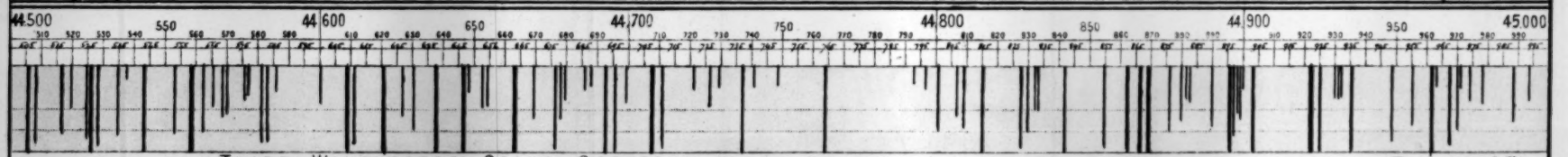
Lemon-Yellow. M. FIEVEZ SOLAR SPECTRUM 1882 *Lemon-Yellow & Citron.*



Lemon-Yellow. FIRST WINCHESTER SOLAR SPECTRUM. June 12 to June 25 1884. *⅓-size nearly of original Record. Long Collimator* *Lemon-Yellow & Citron.*



Lemon-Yellow. SECOND WINCHESTER SOLAR SPECTRUM. June 13 and 26 to 30. 1884. *⅓-size nearly of original Record. Long Collimator.* *Lemon-Yellow & Citron.*



Lemon-Yellow. THIRD WINCHESTER SOLAR SPECTRUM. July 3 to July 19. 1884 *⅓-size nearly of original Record. Short Collimator.* *Lemon-Yellow & Citron.*

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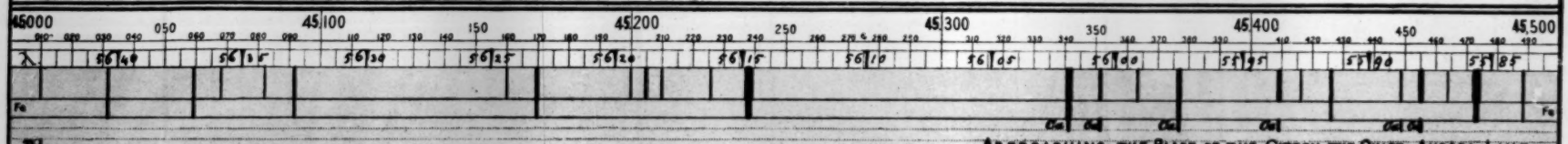
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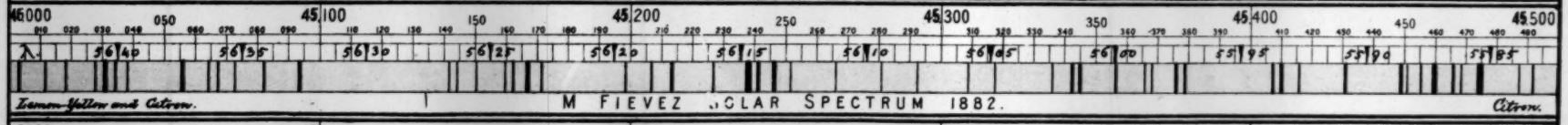
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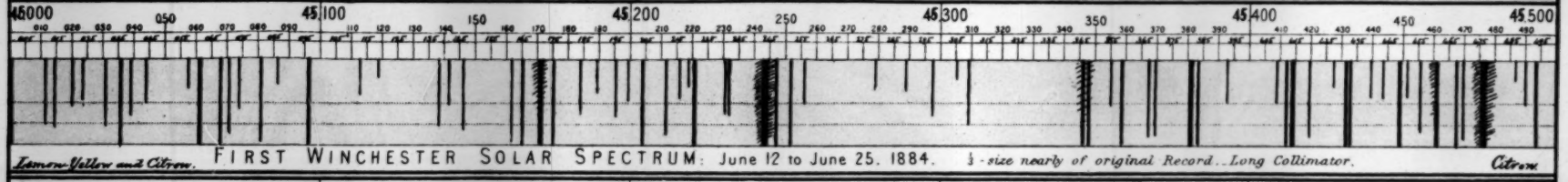
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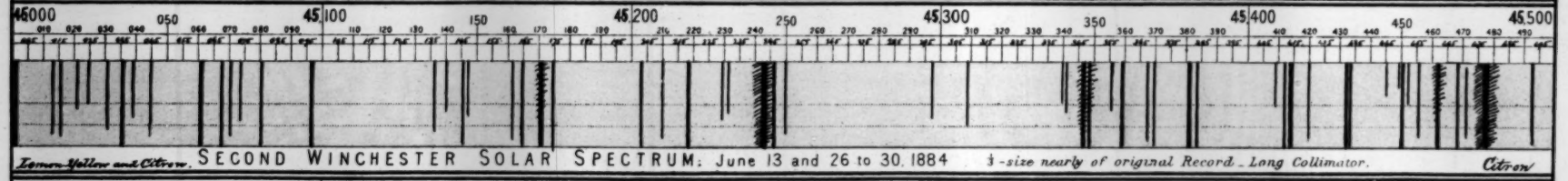
THE VISUAL SOLAR SPECTRUM IN 1884.

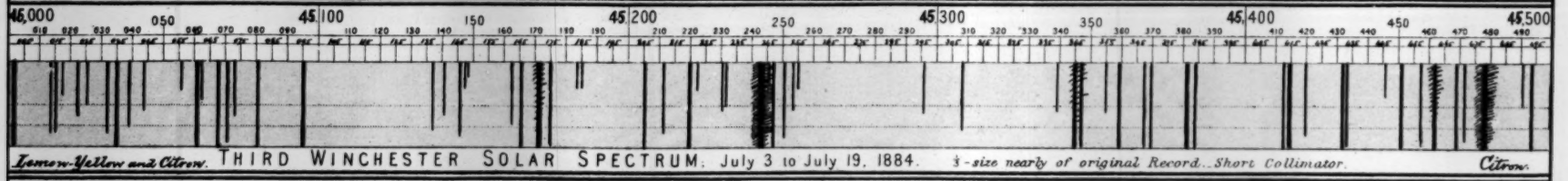
Illustrated by three separate Solar Spectra independently observed at Winchester in June and July, with a Rowland's Grating Spectroscope, by C. Piazzi Smyth, F.R.S.E.
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Photo-Lithographed by W. & A. K. Johnston, Edinburgh & London.

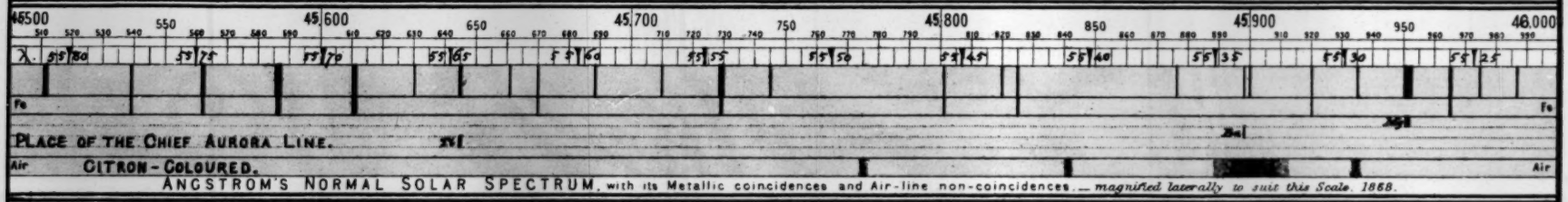
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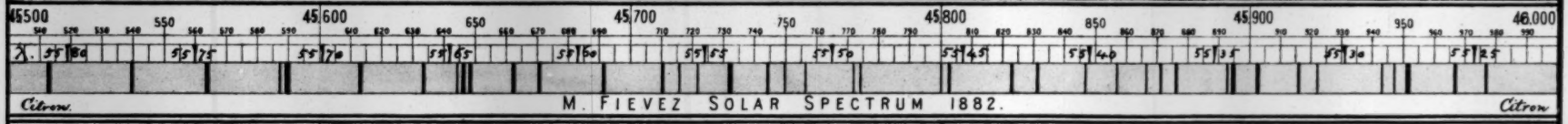
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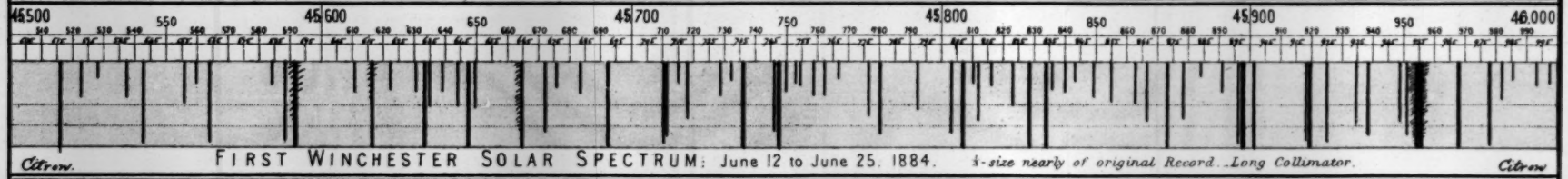
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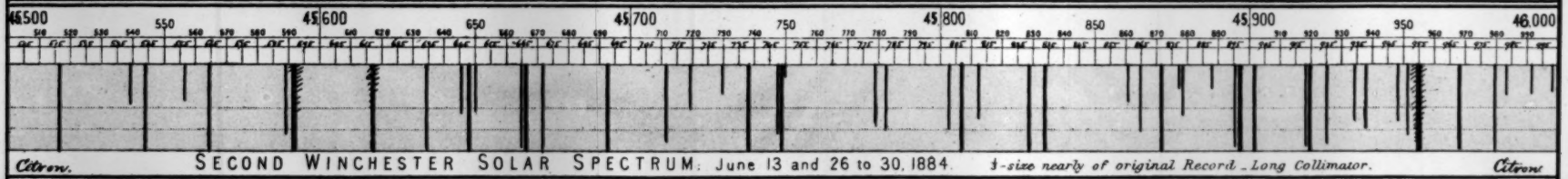
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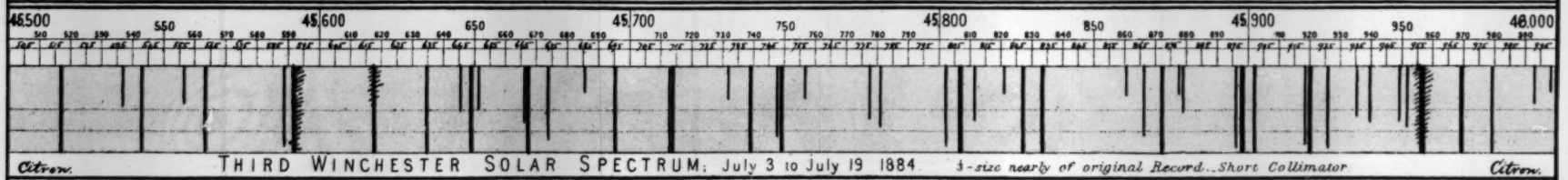
M. FIEVEZ SOLAR SPECTRUM 1882.



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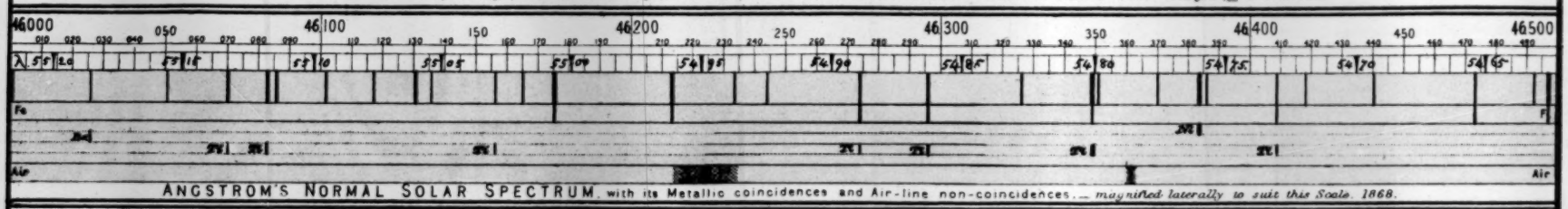
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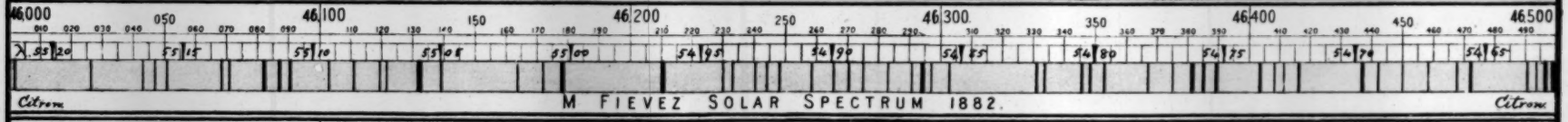
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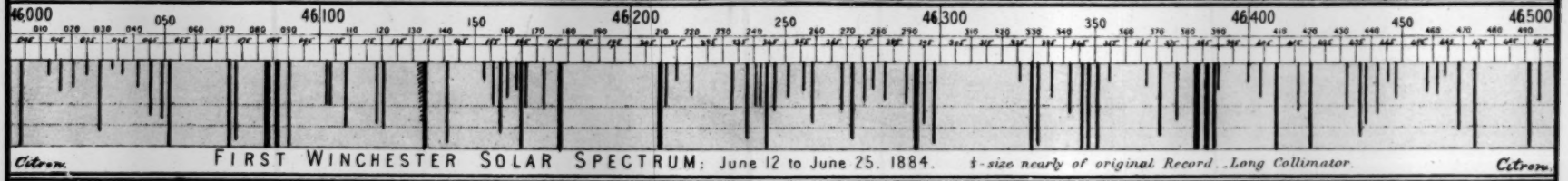
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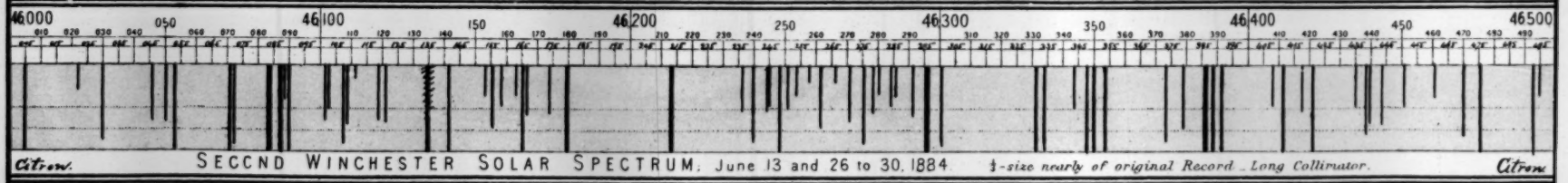
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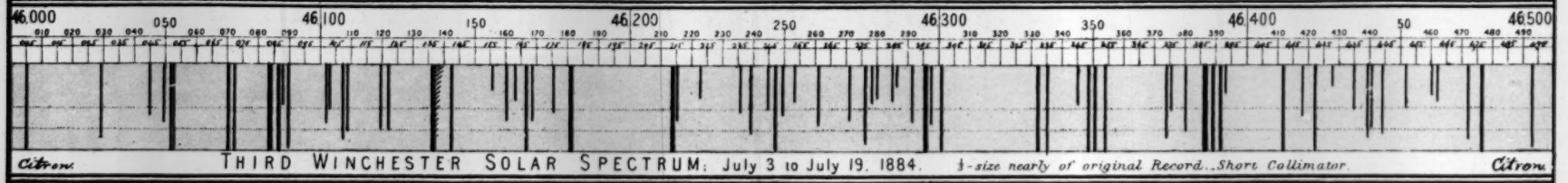
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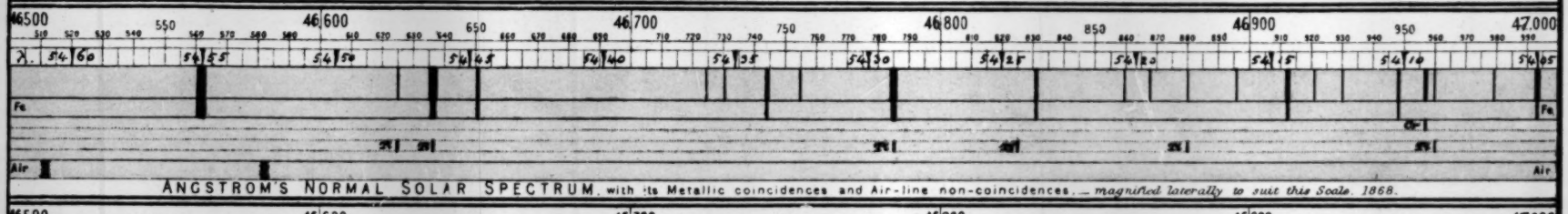
Photo-Lithographed by W. & A. K. Johnston, Edinburgh & London.

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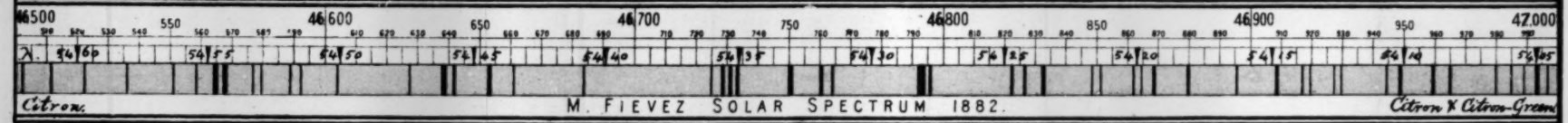
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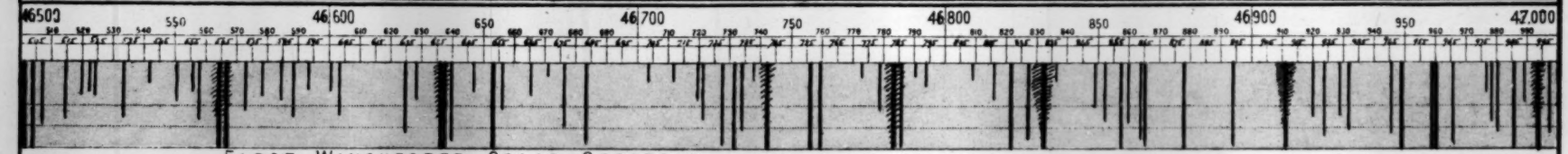
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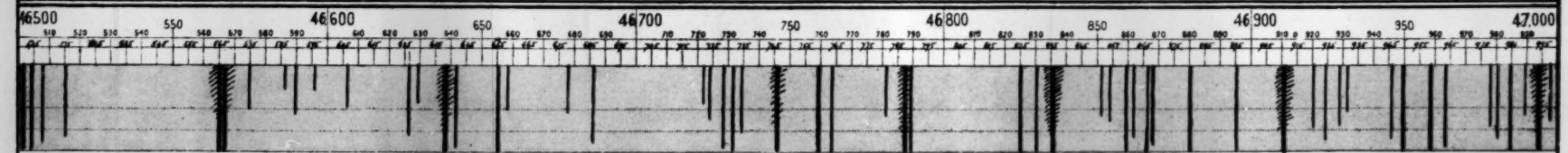
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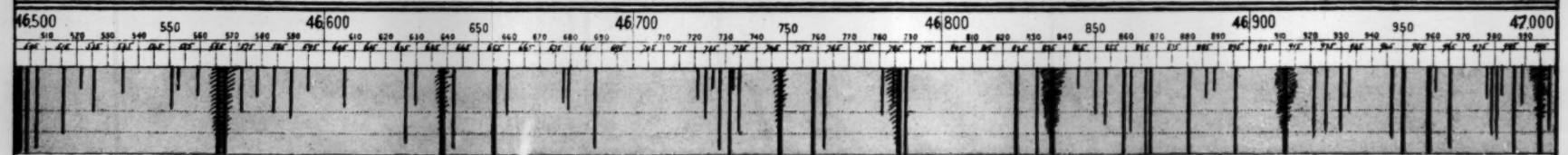
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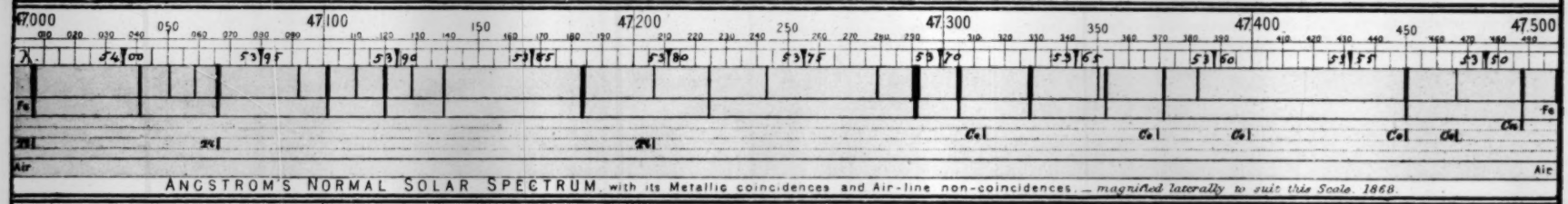
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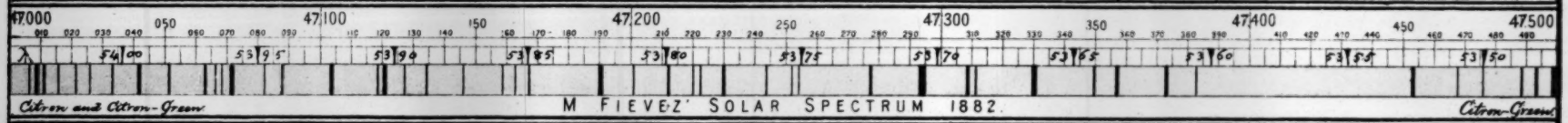
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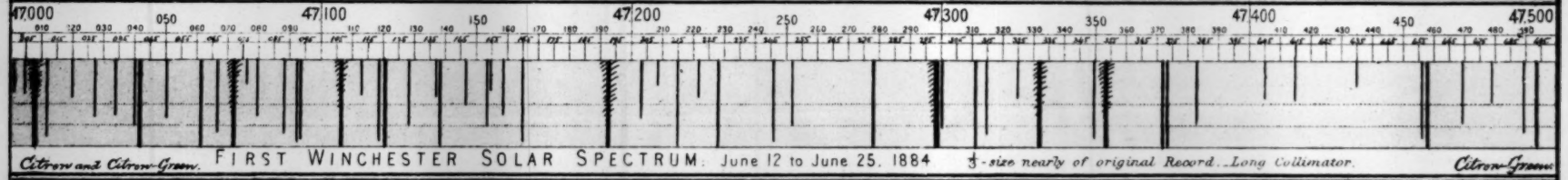
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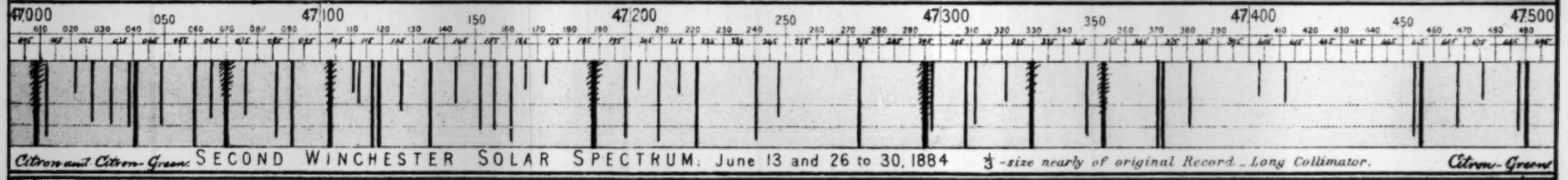
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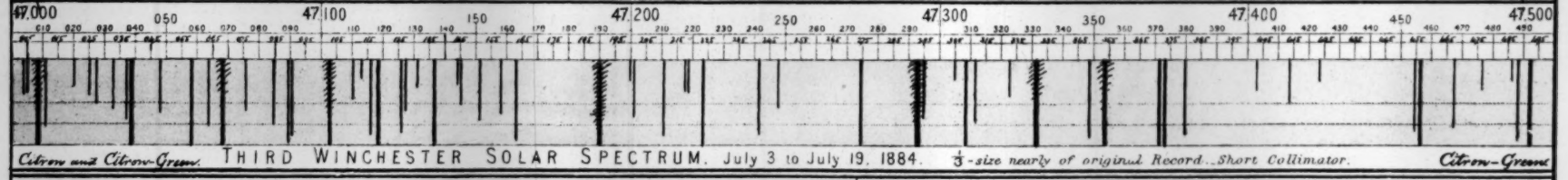
Citron and Citron-Green. M FIEVEZ' SOLAR SPECTRUM 1882. *Citron-Green.*



Citron and Citron-Green. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25, 1884 ⅓-*size nearly of original Record.* — *Long Collimator.* *Citron-Green.*



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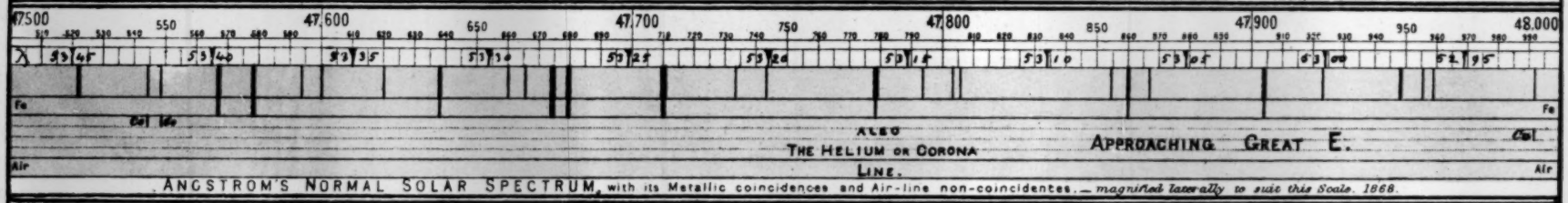
Photo-Lithographed by W. & A.K. Johnston, Edinburgh & London.

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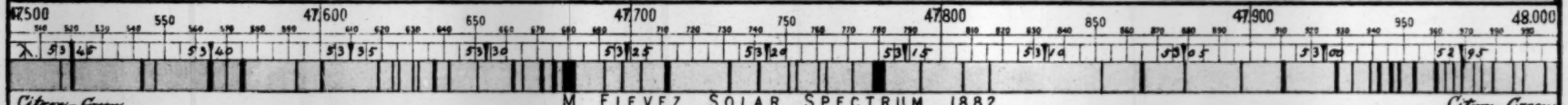
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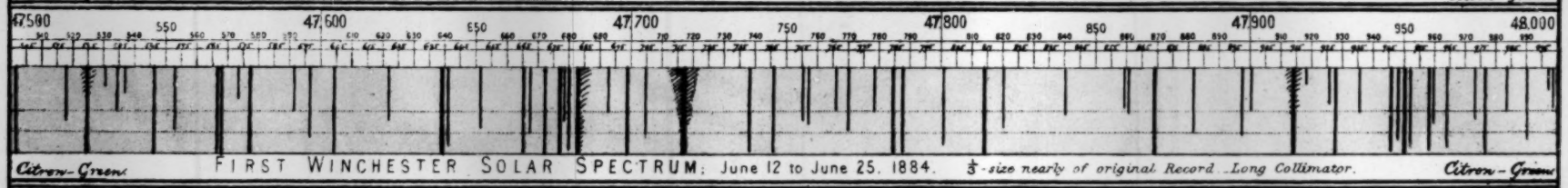
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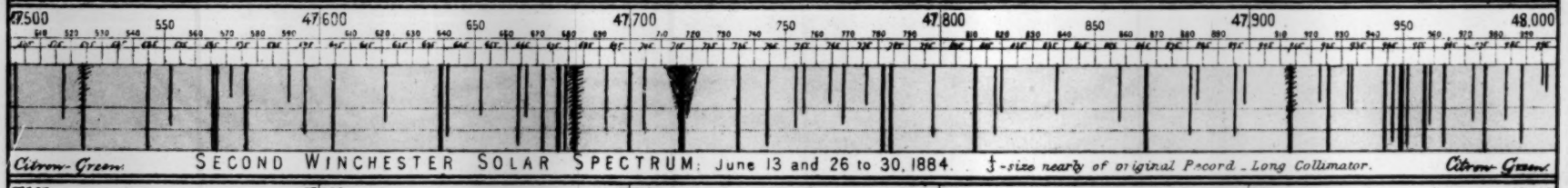
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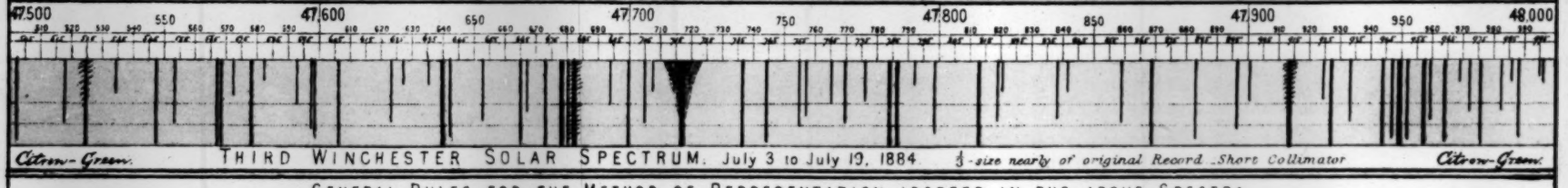
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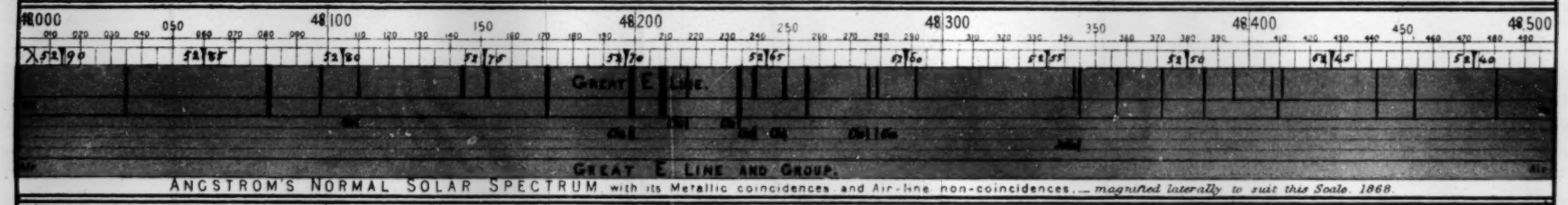
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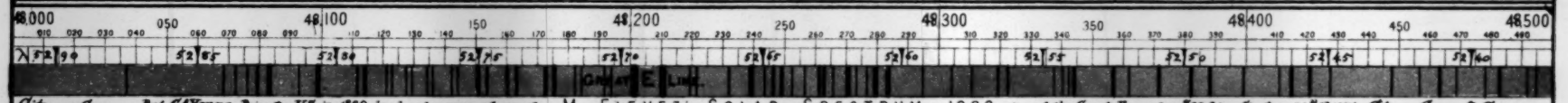
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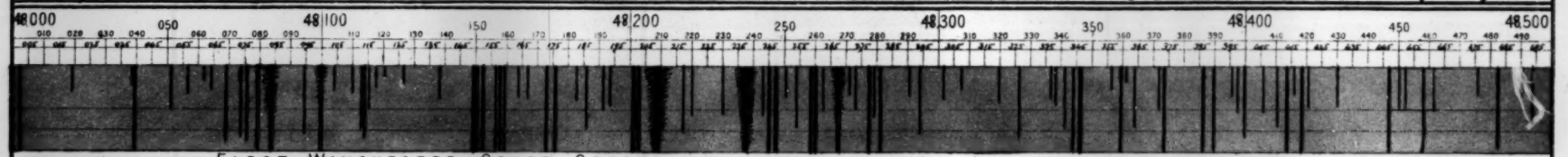
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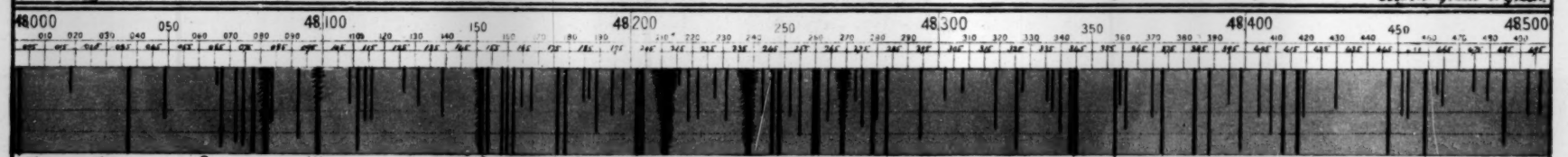
ANGSTROM'S NORMAL SOLAR SPECTRUM with its Metallic coincidences and Air-line non-coincidences. — *magnified laterally to suit this Scale. 1868.*



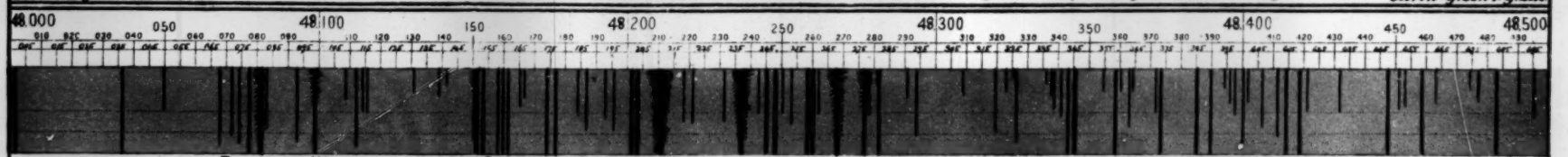
Citron-Green. *Prof. C.A. Young, Princeton U.S. in 1880 produced a more advanced* M. FIEVEZ' SOLAR SPECTRUM 1882. *view of the Great E group, see "Hadden Spectroscopic" pl. XIII. Citron-Green & Green.*



Citron-Green. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25, 1884. ⅓ *size nearly of original Record. Long Collimator.* *Citron-Green & Green.*



Citron-Green. SECOND WINCHESTER SOLAR SPECTRUM: June 13 and 26 to 30, 1884. ⅓ *-size nearly of original Record. Long Collimator* *Citron-Green & Green.*



Citron-Green. THIRD WINCHESTER SOLAR SPECTRUM: July 3 to July 19, 1884. ⅓ *-size nearly of original Record. Short Collimator.* *Citron-Green & Green.*

GENERAL RULES FOR THE METHOD OF REPRESENTATION ADOPTED IN THE ABOVE SPECTRA.

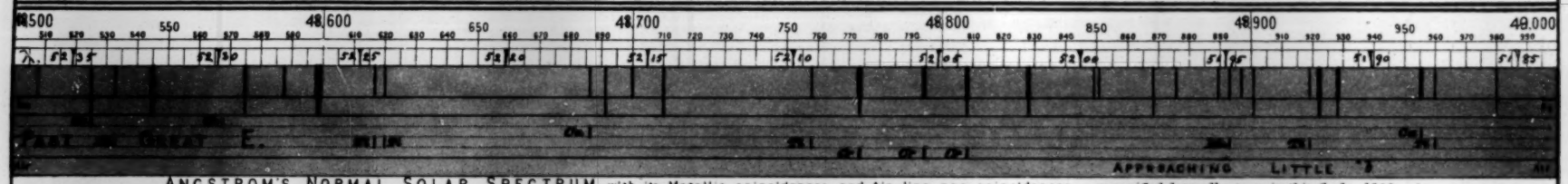
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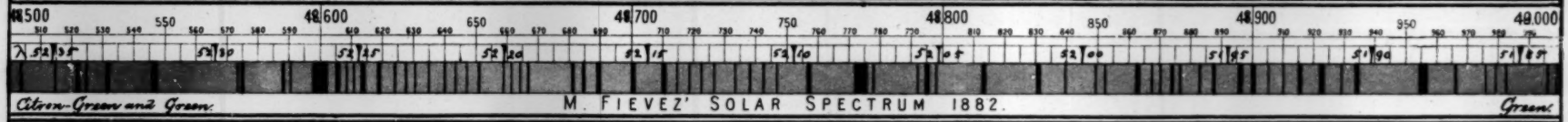
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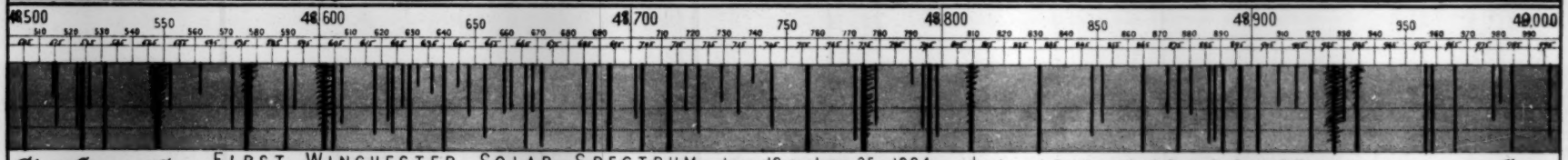
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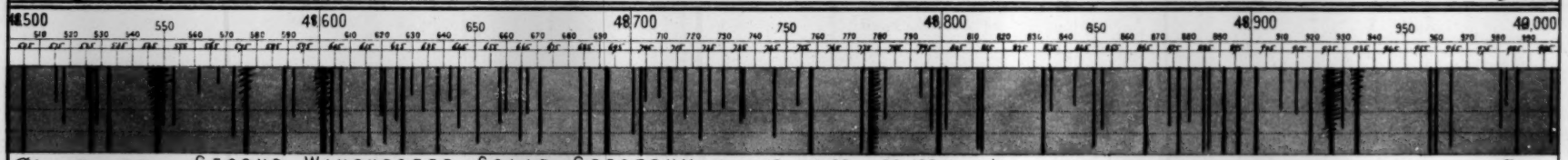
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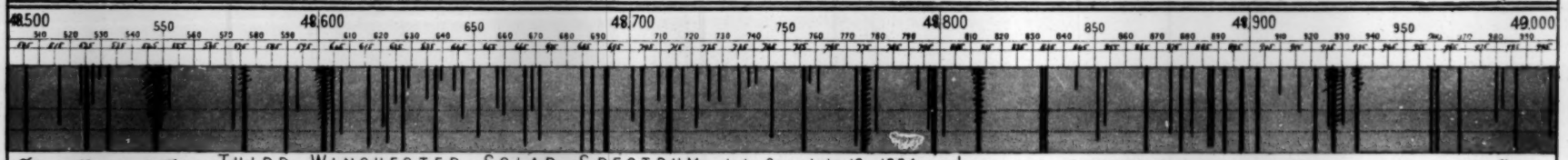
Citron-Green and Green. M. FIEVEZ' SOLAR SPECTRUM 1882. *Green.*



Citron-Green and Green. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25, 1884. *⅓-size nearly of original Record.—Long Collimator.* *Green.*



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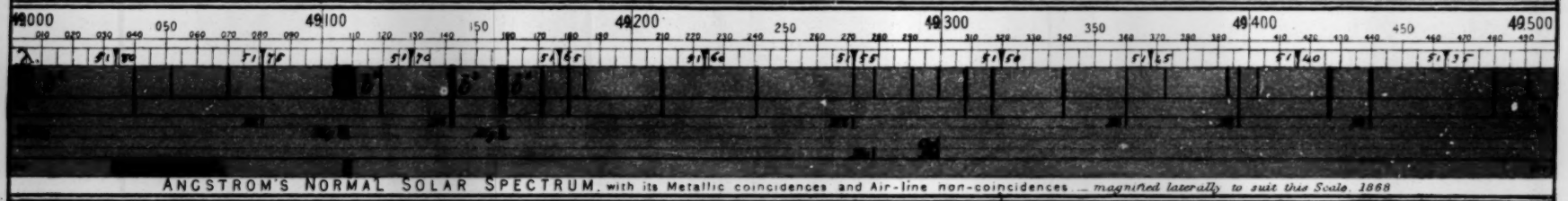
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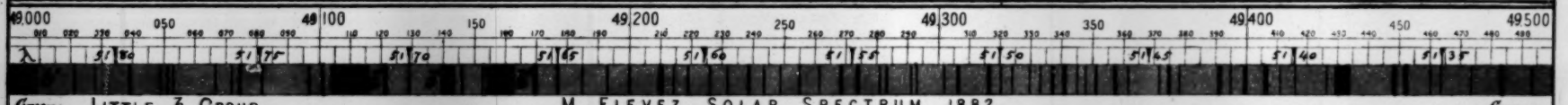
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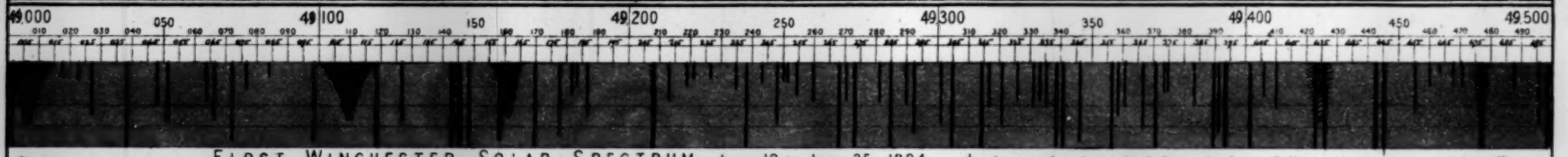
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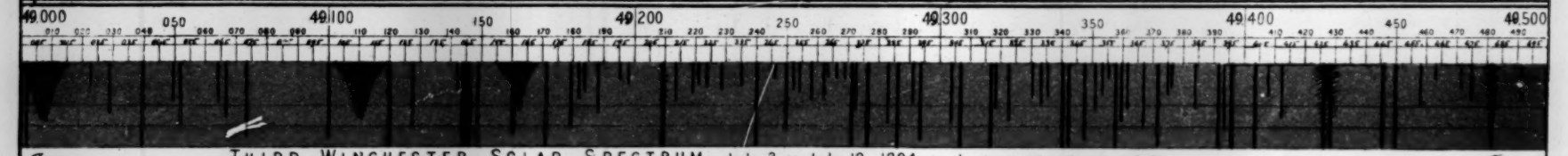
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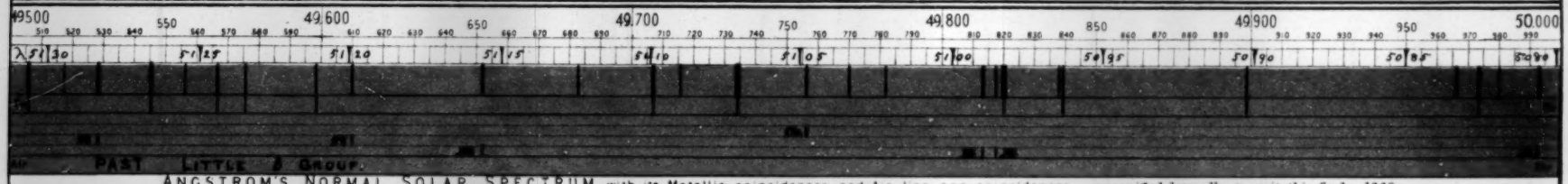
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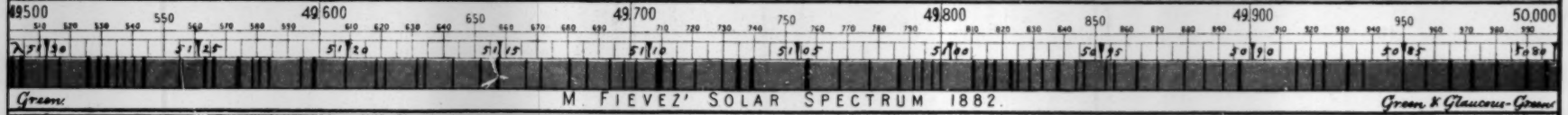
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THE VISUAL SOLAR SPECTRUM IN 1884.

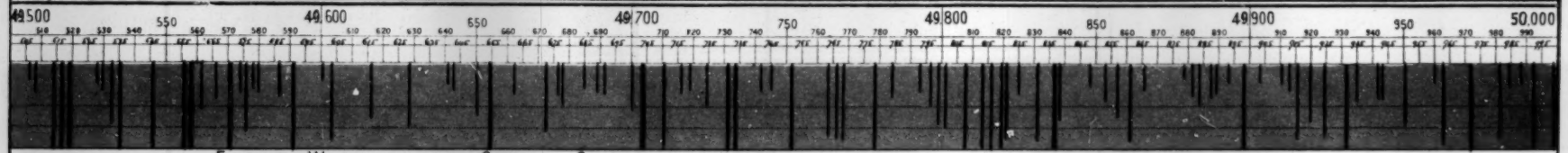
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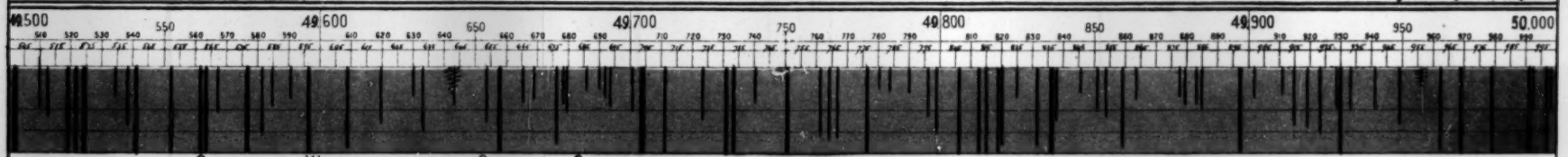
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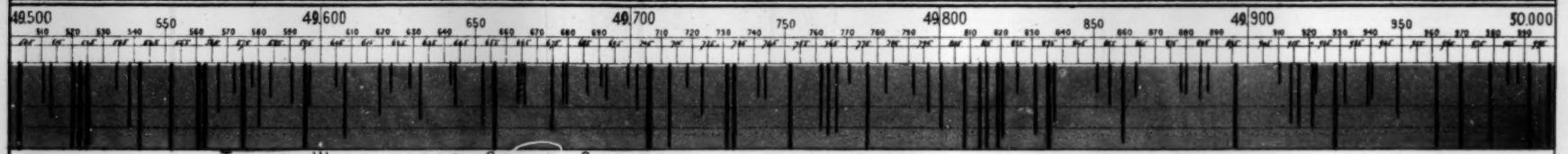
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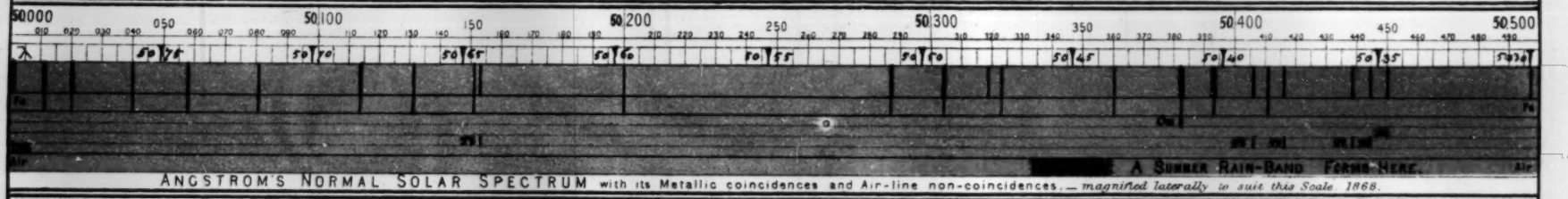
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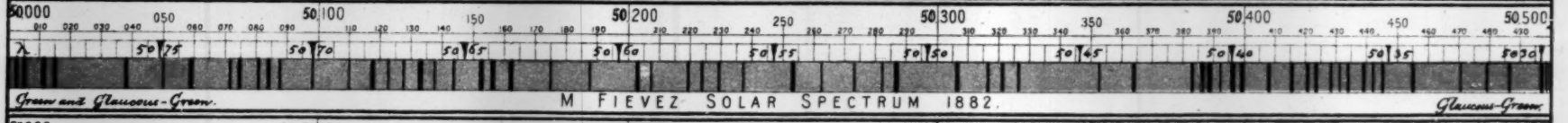
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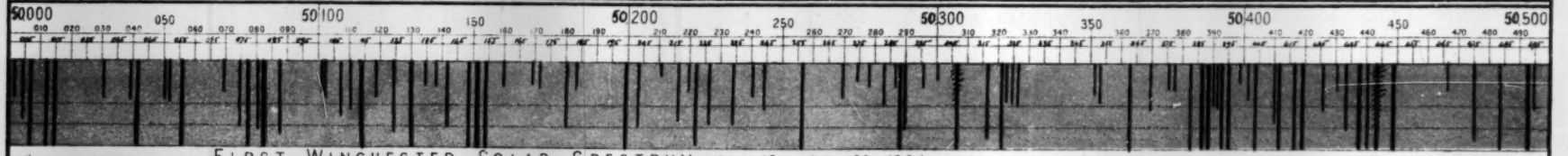
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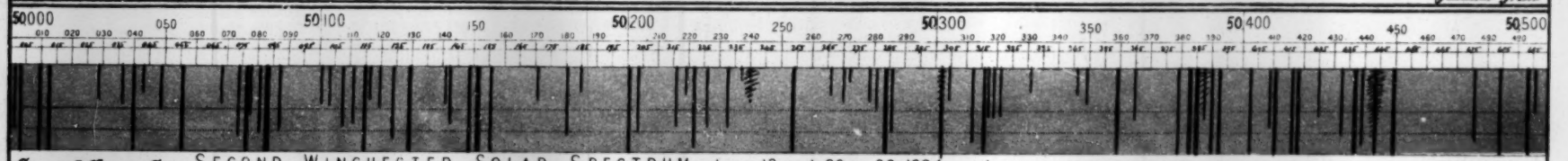
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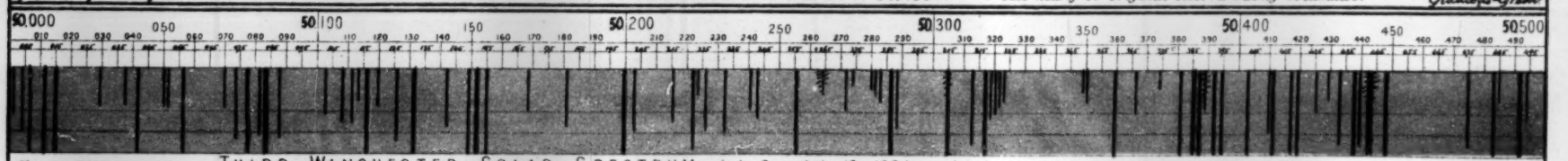
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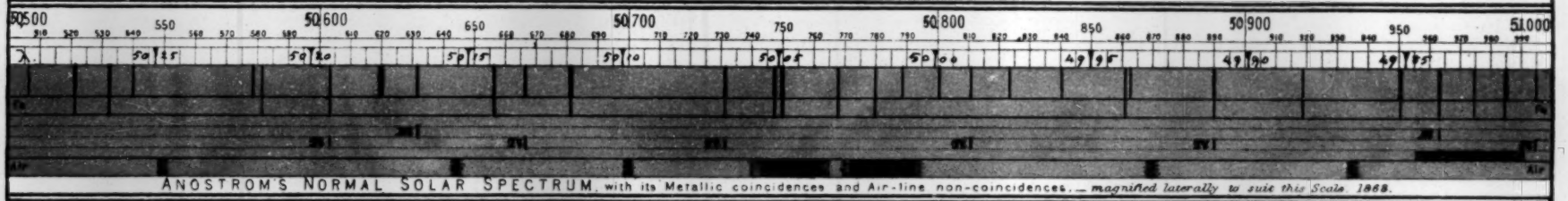
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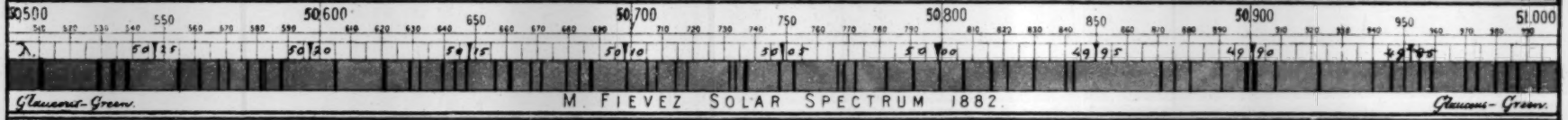
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THE VISUAL SOLAR SPECTRUM IN 1884.

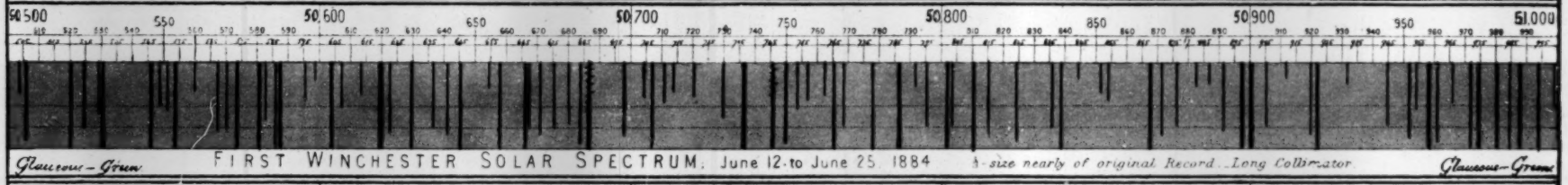
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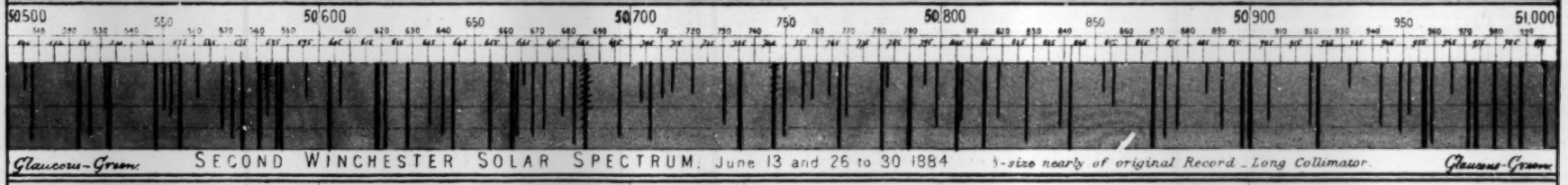
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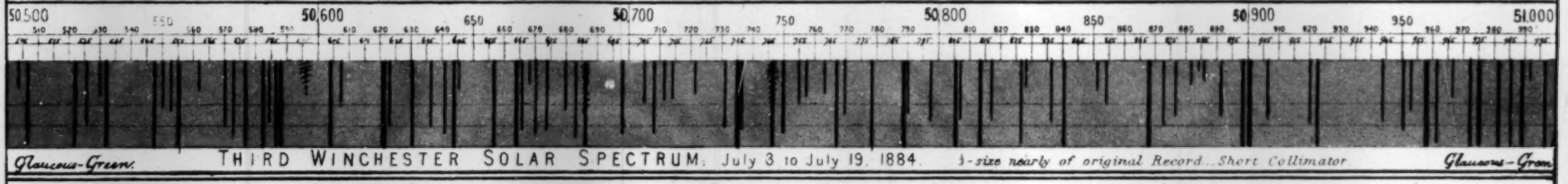
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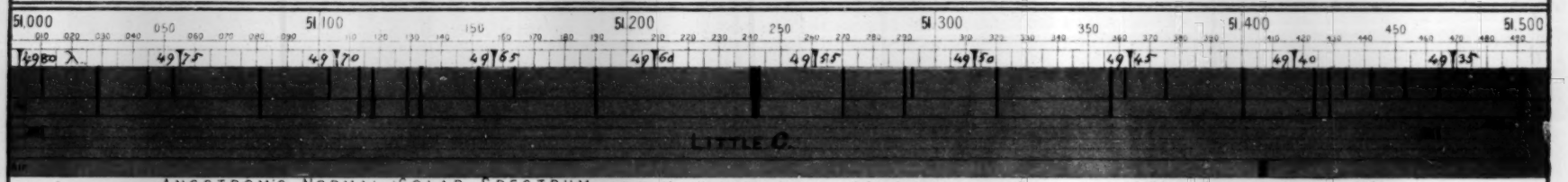
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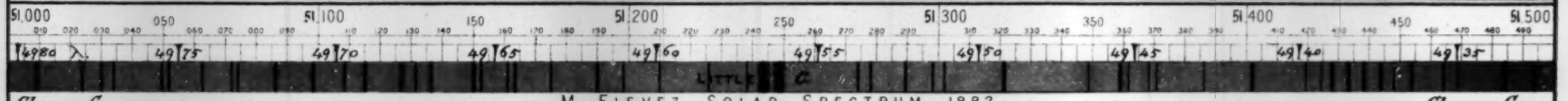
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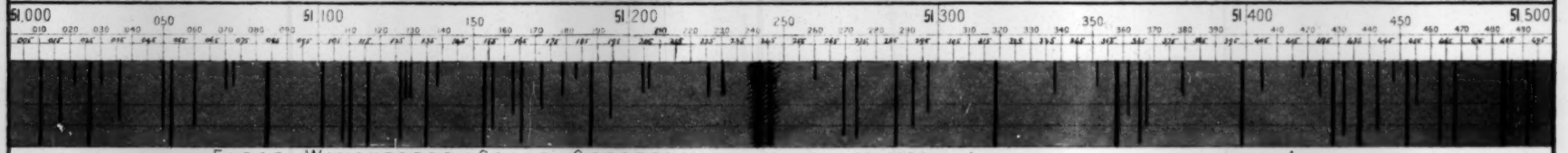
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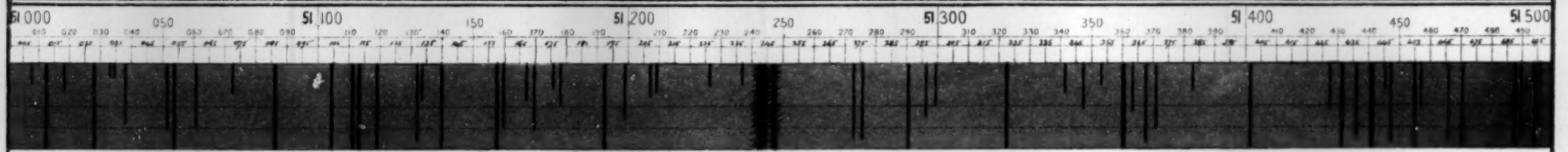
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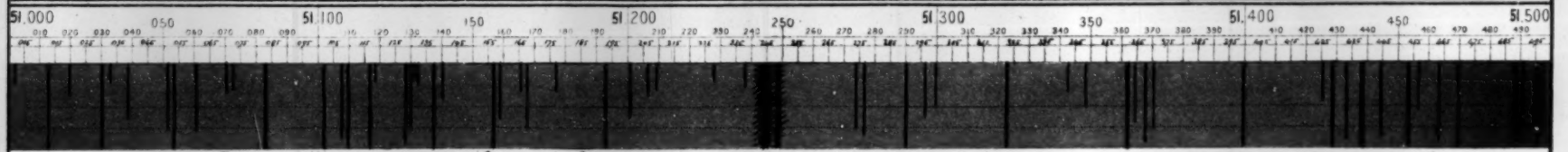
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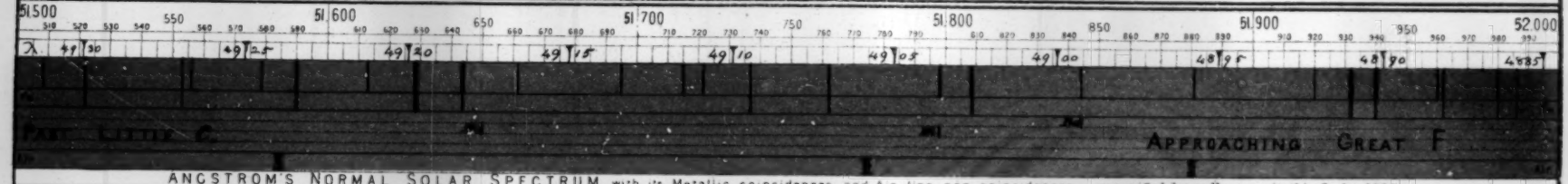
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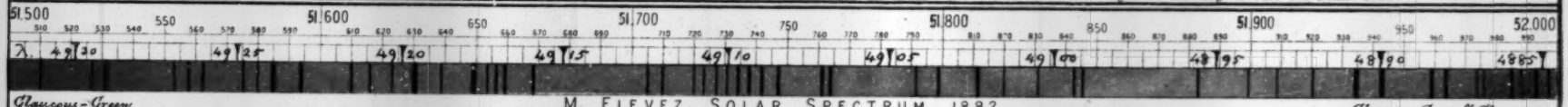


THE VISUAL SOLAR SPECTRUM IN 1884.

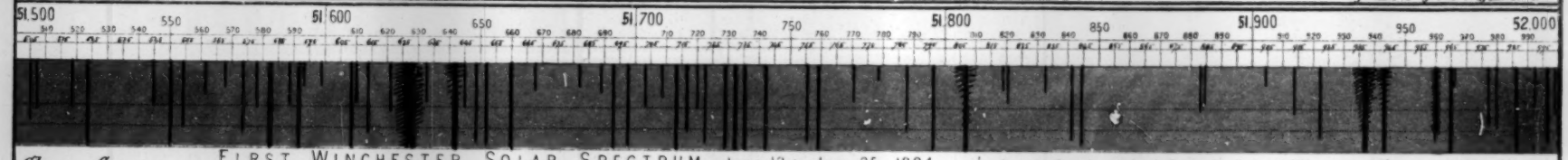
Illustrated by three separate Solar Spectra independently observed at Winchester in June and July, with a Rowland's Grating Spectroscope, by C. Piazzi Smyth, F.R.S.E.
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ANGSTROM'S NORMAL SOLAR SPECTRUM with its Metallic coincidences and Air-line non-coincidences.—*magnified laterally to suit this Scale. 1868*



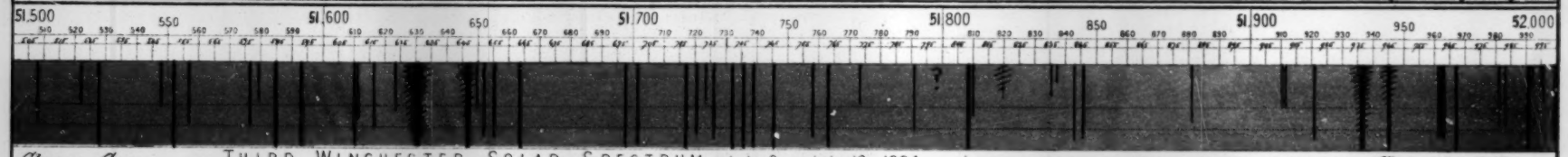
Glaucous-Green. M. FIEVEZ SOLAR SPECTRUM 1882. *Glaucous-Green & Glaucous.*



Glaucous-Green. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25, 1884. *⅓-size nearly of original Record.—Long Collimator.* *Glaucous-Green & Glaucous.*



Glaucous-Green. SECOND WINCHESTER SOLAR SPECTRUM: June 13 and 26 to 30, 1884 *⅓-size nearly of original Record.—Long Collimator.* *Glaucous-Green & Glaucous.*



Glaucous-Green. THIRD WINCHESTER SOLAR SPECTRUM: July 3 to July 19, 1884. *⅓-size nearly of original Record.—Short Collimator.* *Glaucous-Green & Glaucous.*

GENERAL RULES FOR THE METHOD OF REPRESENTATION ADOPTED IN THE ABOVE SPECTRA.

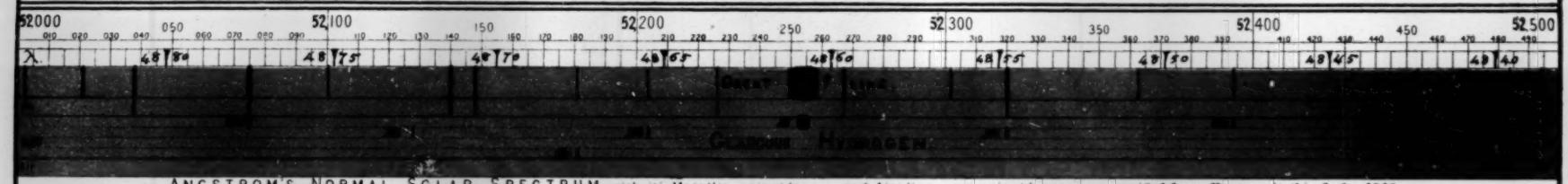
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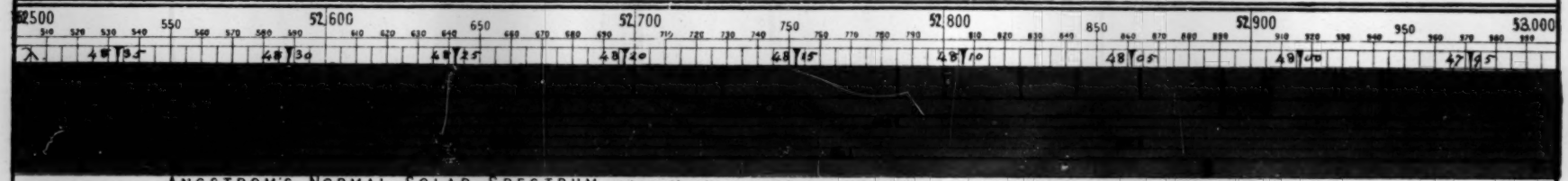

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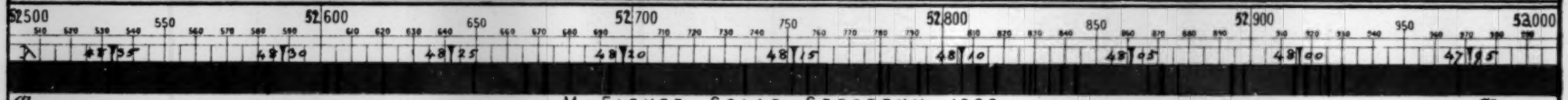
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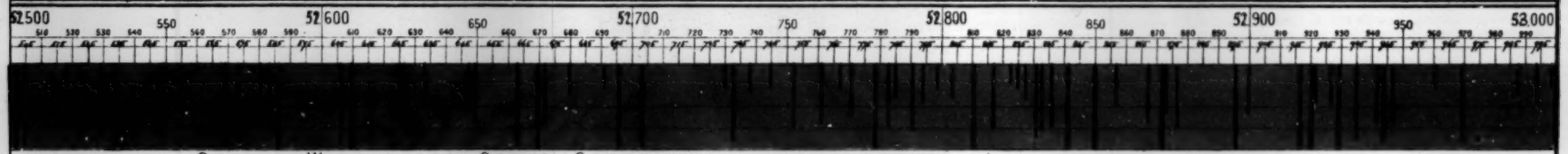
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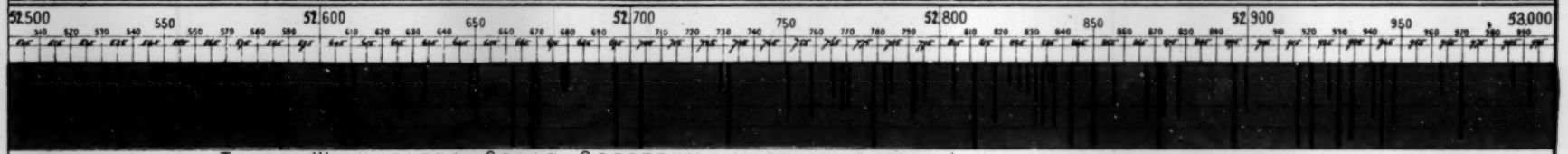
Glaucous. M. FIEVEZ SOLAR SPECTRUM 1882. Glaucous.



Glaucous. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25. 1884. $\frac{1}{3}$ *-size nearly of original Record. – Long Collimator* Glaucous.



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Glaucous. THIRD WINCHESTER SOLAR SPECTRUM: July 3 to July 19. 1884. $\frac{1}{3}$ *-size nearly of original Record. – Short Collimator.* Glaucous.

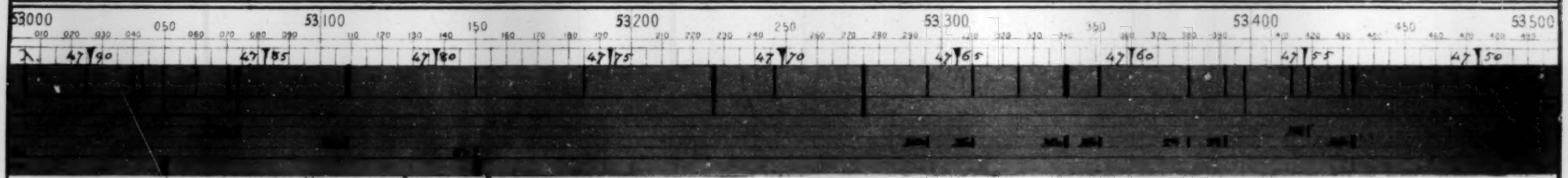
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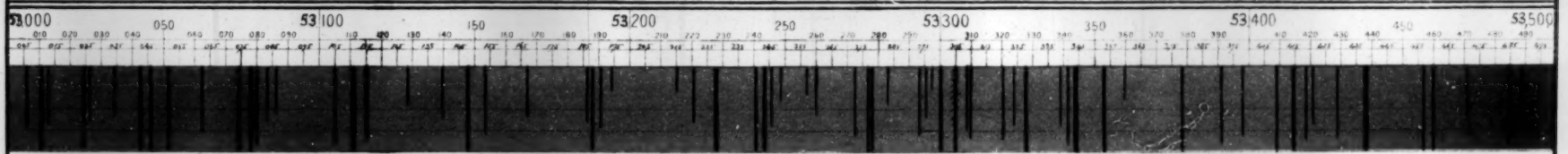
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Glaucous. M. FIEVEZ SOLAR SPECTRUM 1882 Glaucous.



Glaucous. FIRST WINCHESTER SOLAR SPECTRUM. June 12 to June 25. 1884 ½-size nearly of original Record. Long Collimator. Glaucous.



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Glaucous. THIRD WINCHESTER SOLAR SPECTRUM. July 3 to July 19. 1884 ½ size nearly of original Record. Short Collimator. Glaucous.

GENERAL RULES FOR THE METHOD OF REPRESENTATION ADOPTED IN THE ABOVE SPECTRA

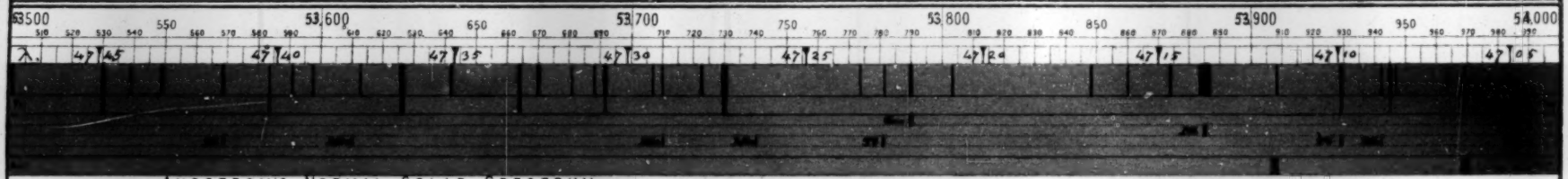
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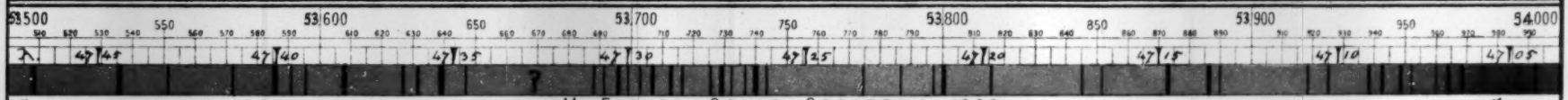
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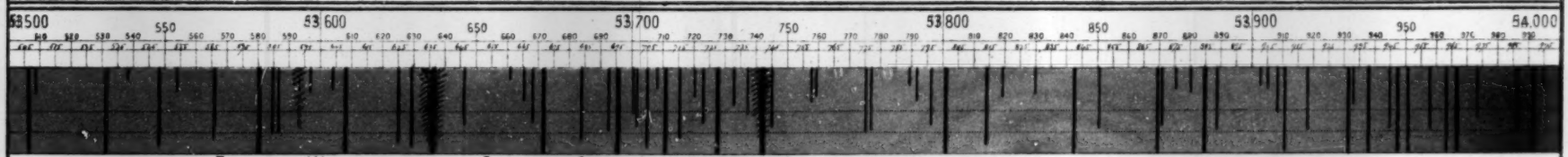
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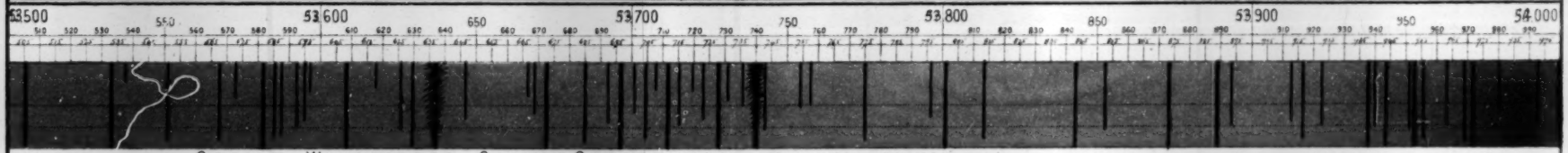
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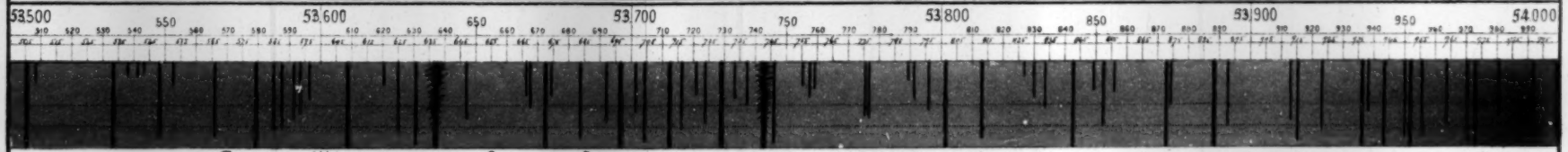
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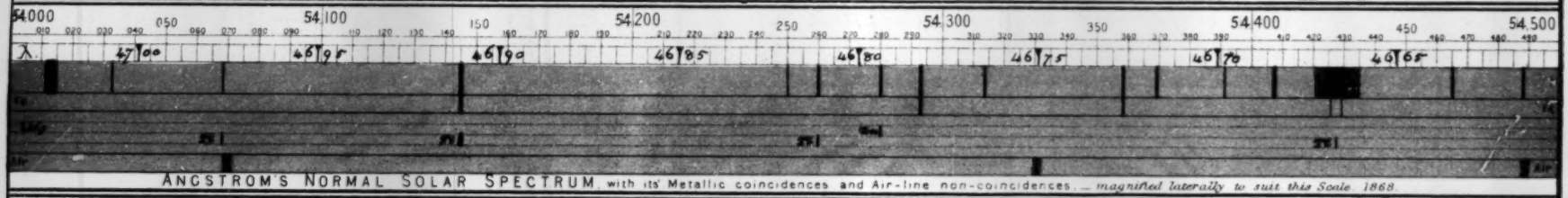
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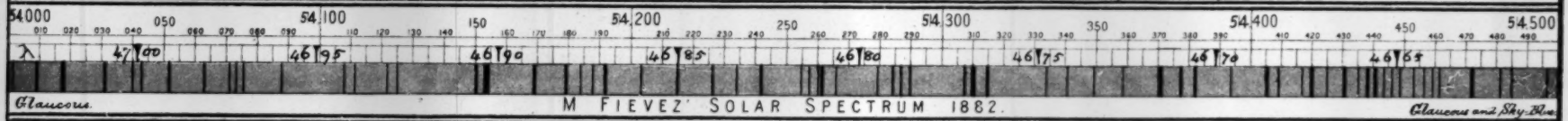
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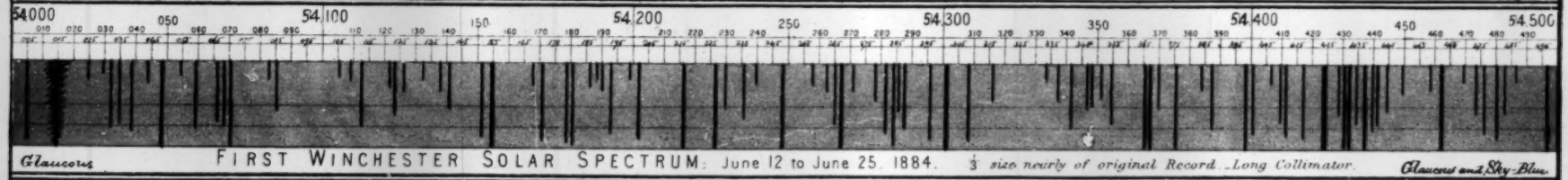
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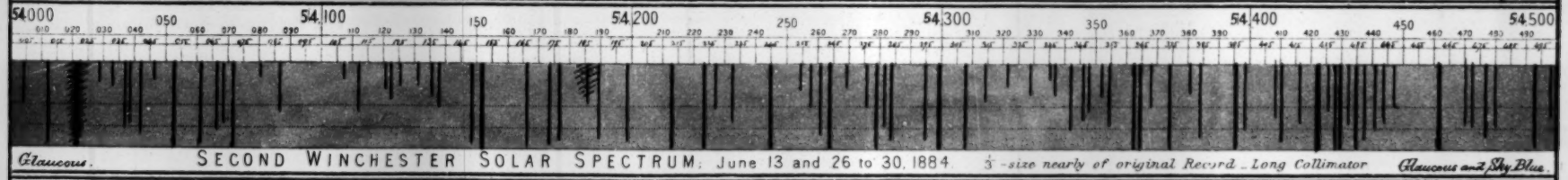
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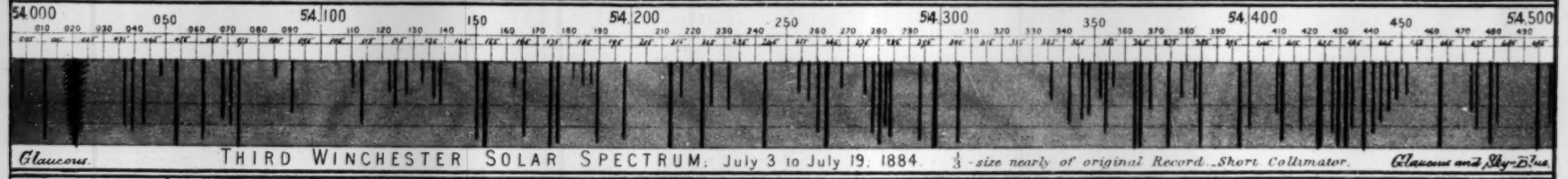
Glaucous. M. FIEVEZ' SOLAR SPECTRUM 1882. Glaucous and Sky-Blue.



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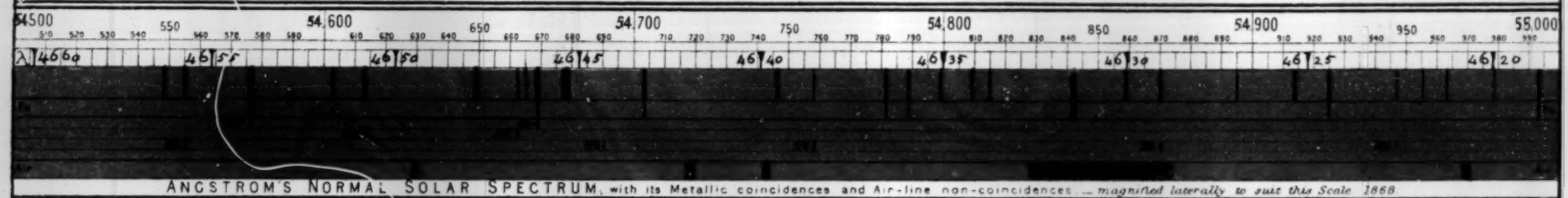
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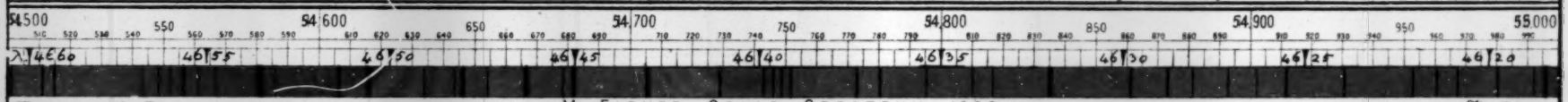
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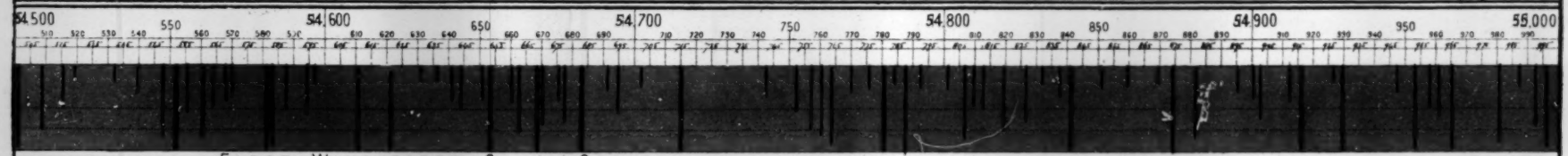
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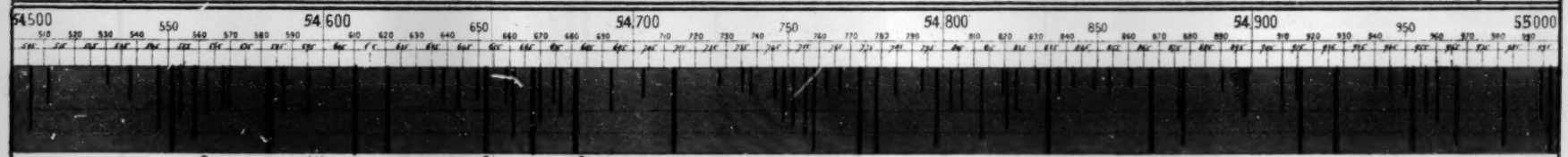
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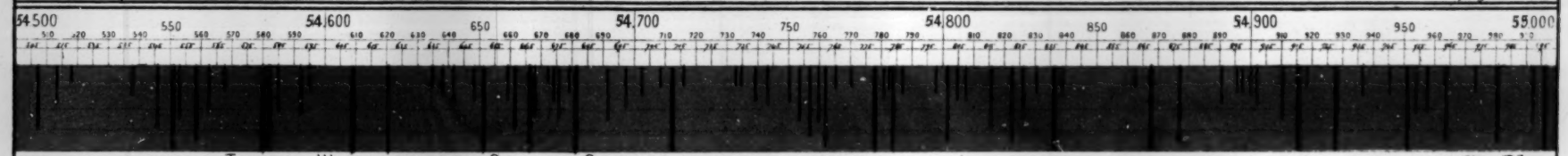
Glaucous and Sky-Blue. M. FIEVEZ SOLAR SPECTRUM 1882. *Sky-Blue.*



Glaucous and Sky-Blue. FIRST WINCHESTER SOLAR SPECTRUM. June 12 to June 25. 1884. *⅓ size nearly of original Record. Long Collimator.* *Sky-Blue.*



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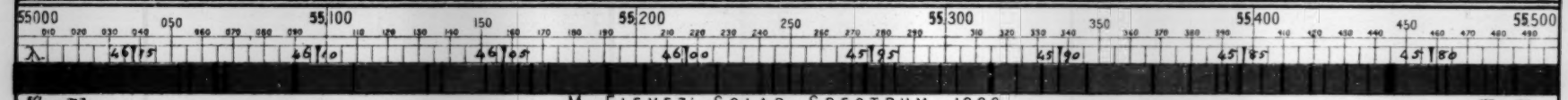
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Sky-Blue. M FIEVEZ' SOLAR SPECTRUM 1882. *Sky-Blue.*



Sky-Blue. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25. 1884. *⅓ size nearly of original Record. – Long Collimator.* *Sky-Blue.*



Sky-Blue. SECOND WINCHESTER SOLAR SPECTRUM: June 13 and 26 to 30. 1884. *⅓ size nearly of original Record. – Long Collimator.* *Sky-Blue.*



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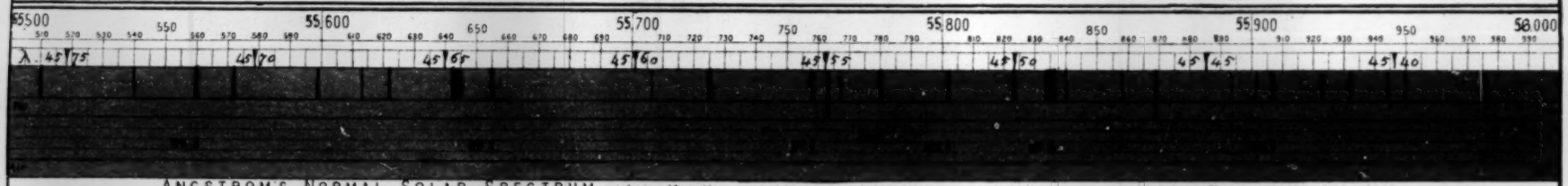
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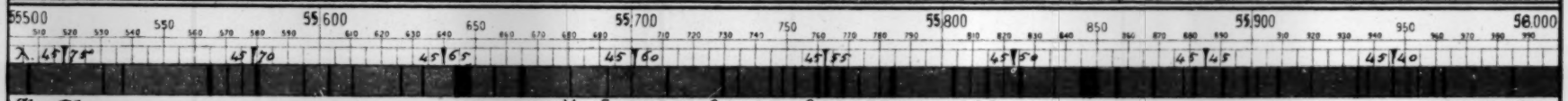
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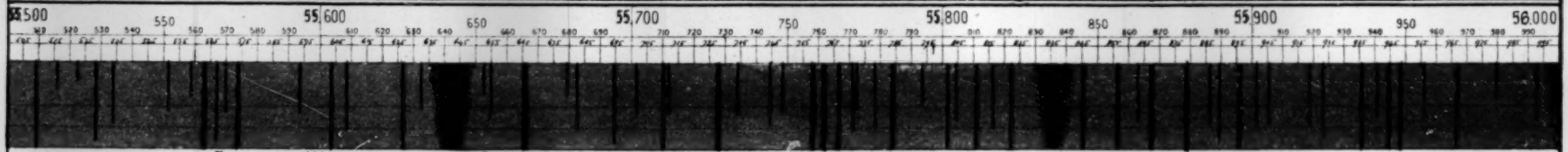
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Sky-Blue. M. FIEVEZ SOLAR SPECTRUM. 1882. Sky-Blue.



Sky-Blue. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25. 1884. *3-size nearly of original Record. — Long Collimator.* Sky-Blue.



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Sky-Blue. THIRD WINCHESTER SOLAR SPECTRUM: July 3 to July 19. 1884. *3-size nearly of original Record. — Short Collimator.* Sky-Blue.

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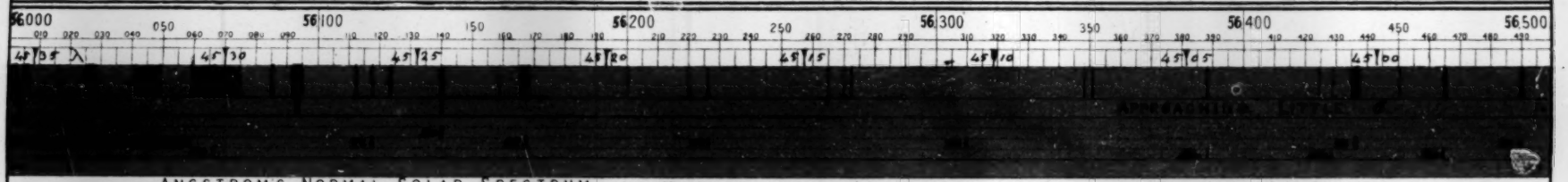
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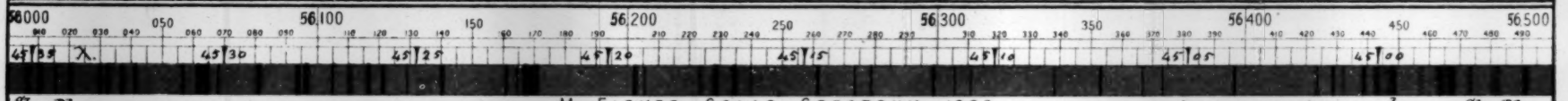
THE VISUAL SOLAR SPECTRUM IN 1884

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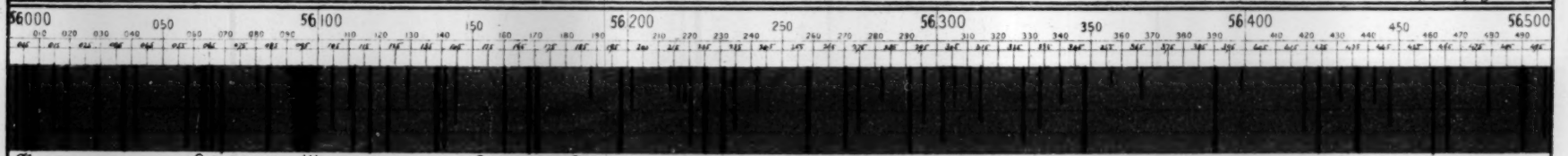
ANGSTROM'S NORMAL SOLAR SPECTRUM, with its Metallic coincidences and Air-line non-coincidences.—*magnified laterally to suit this Scale. 1868.*



Sky-Blue. M FIEVEZ SOLAR SPECTRUM 1882. APPROACHING LITTLE *d*. *Sky-Blue.*



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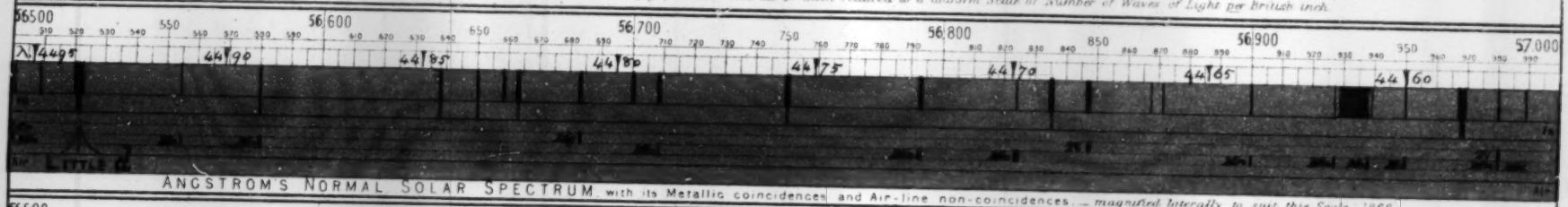
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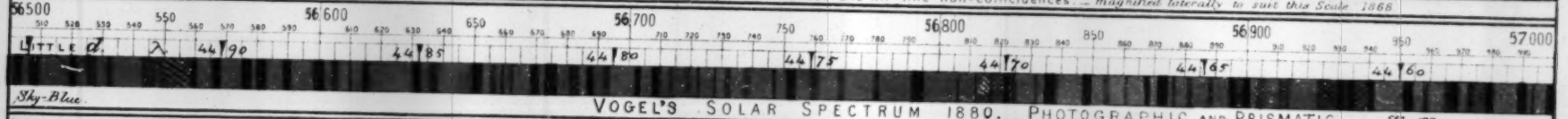
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THE VISUAL SOLAR SPECTRUM IN 1884.

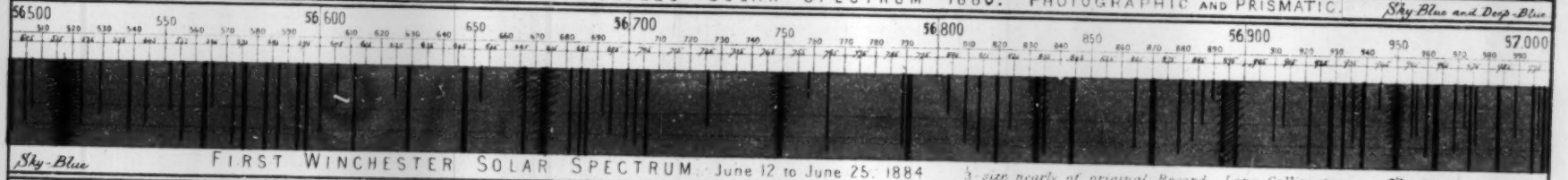
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Sky-Blue. VOGEL'S SOLAR SPECTRUM 1880. PHOTOGRAPHIC AND PRISMATIC. Sky-Blue and Deep-Blue.



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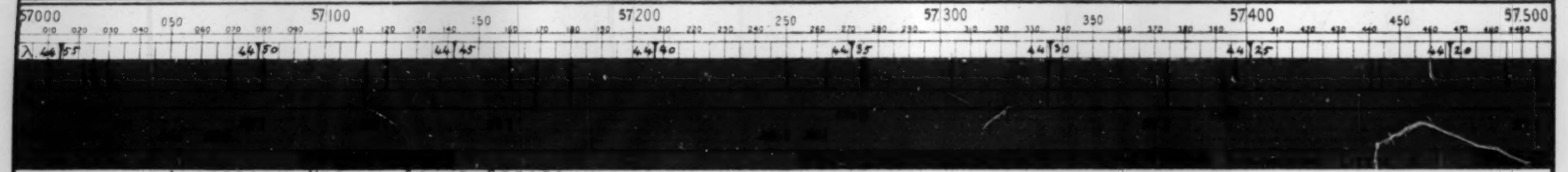
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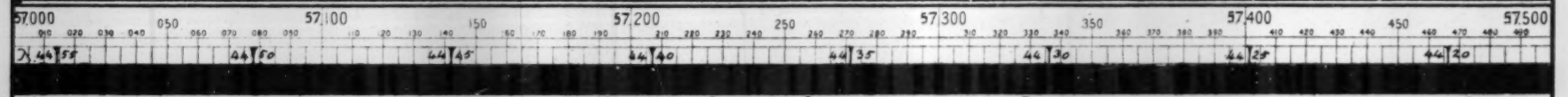
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THE VISUAL SOLAR SPECTRUM IN 1884.

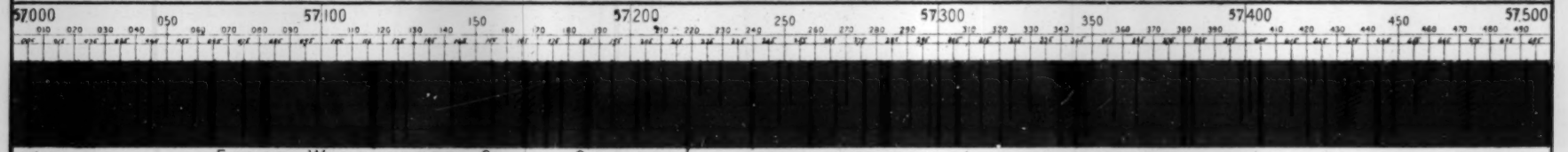
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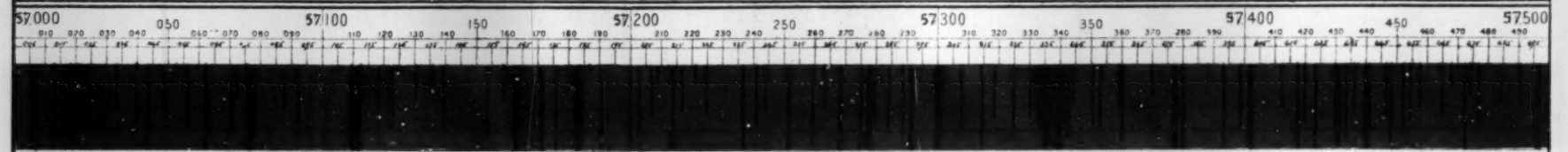
Sky-Blue and Deep-Blue. VOGEL'S SOLAR SPECTRUM 1880. PHOTOGRAPHIC. APPROACHING LITTLE *e*. *Deep-Blue.*



Sky-Blue and Deep-Blue. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25. 1884 ⅓ *-size nearly of original Record. Long Collimator.* *Deep-Blue*



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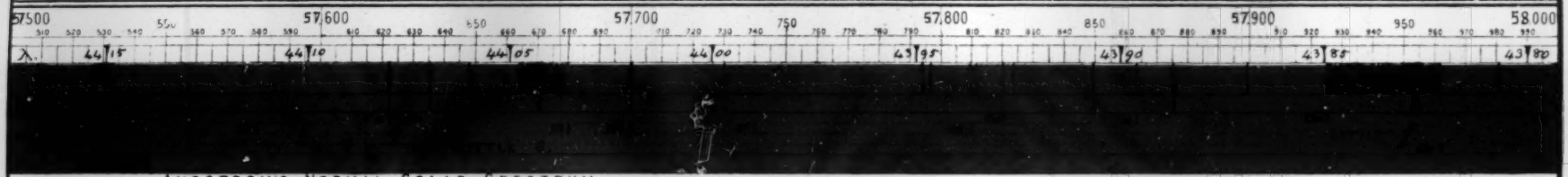
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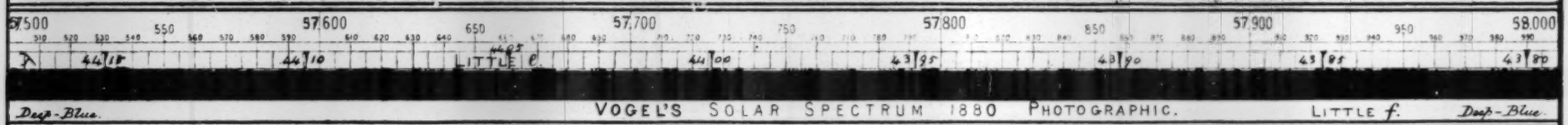


THE VISUAL SOLAR SPECTRUM IN 1884

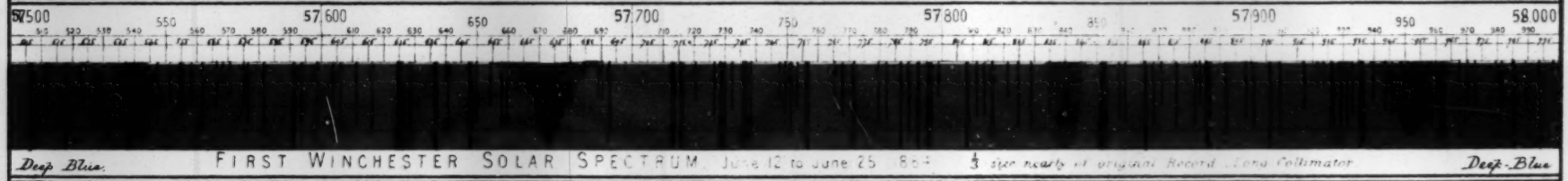
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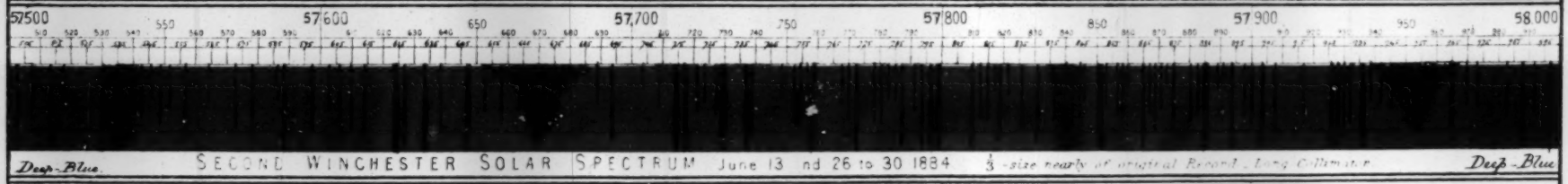
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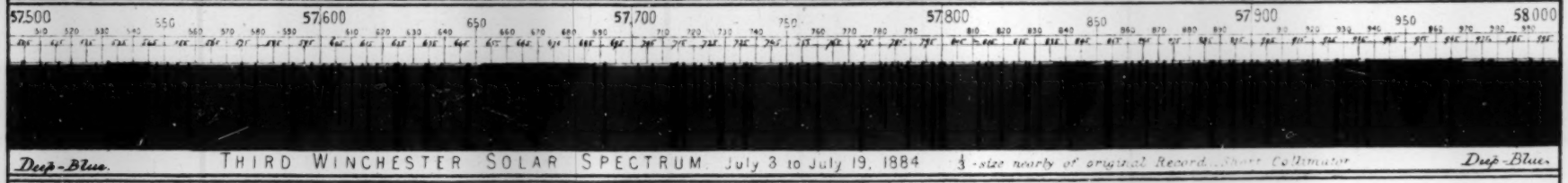
Deep-Blue. VOGEL'S SOLAR SPECTRUM 1880 PHOTOGRAPHIC. LITTLE *f*. Deep-Blue.



Deep Blue. FIRST WINCHESTER SOLAR SPECTRUM June 12 to June 25 1884 ⅓ size nearly of original Record. Long Collimator Deep-Blue.



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Deep-Blue. THIRD WINCHESTER SOLAR SPECTRUM. July 3 to July 19, 1884 ⅓-size nearly of original Record. Short Collimator Deep-Blue.

GENERAL RULES FOR THE METHOD OF REPRESENTATION ADOPTED IN THE ABOVE SPECTRA

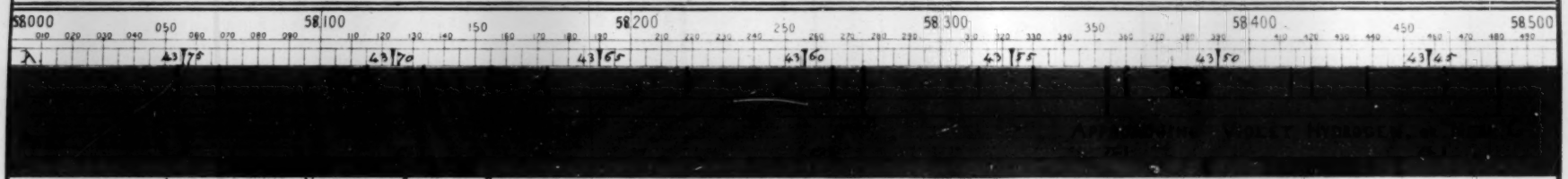
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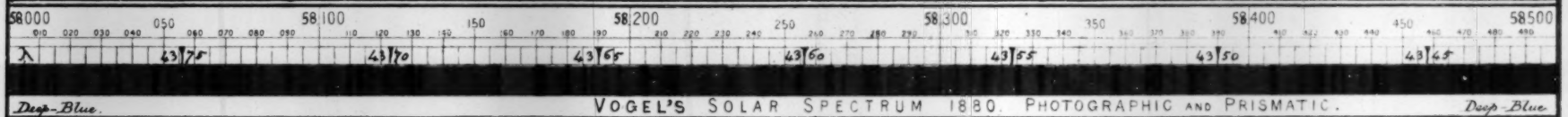
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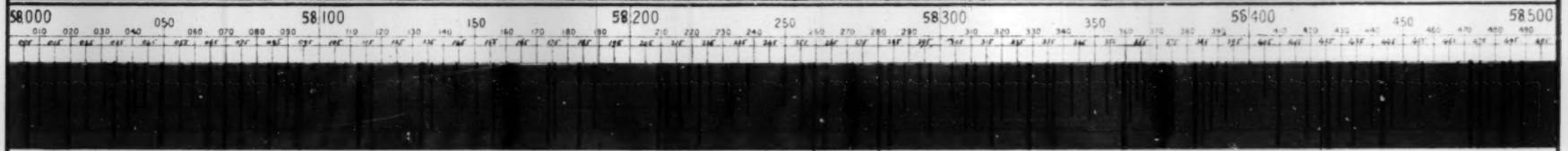
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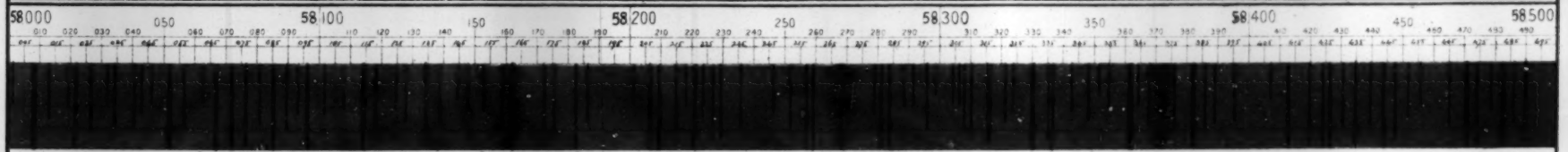
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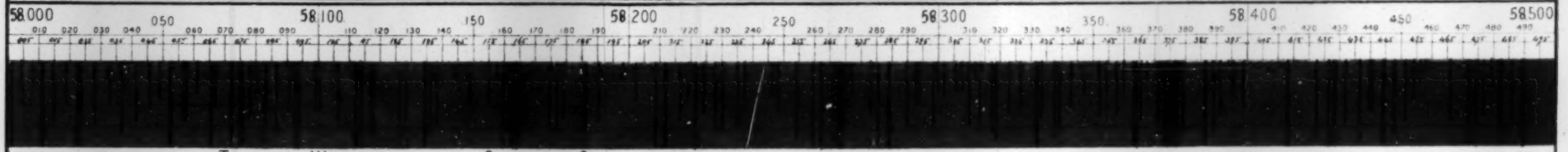
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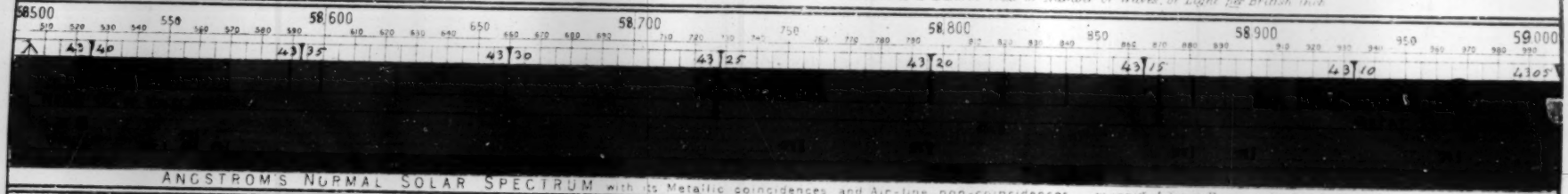
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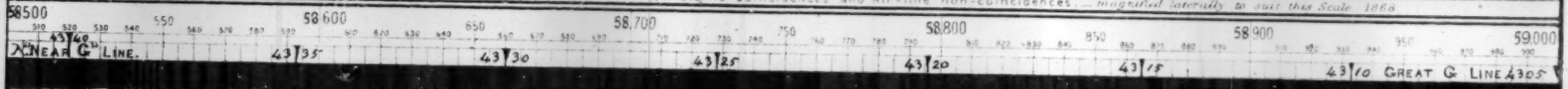
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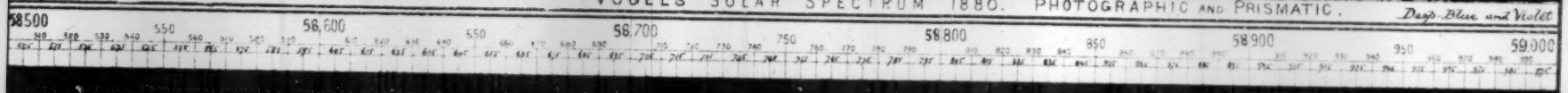
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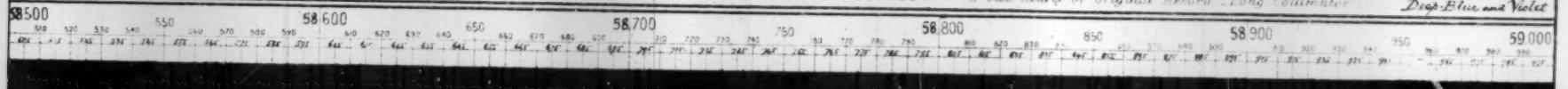
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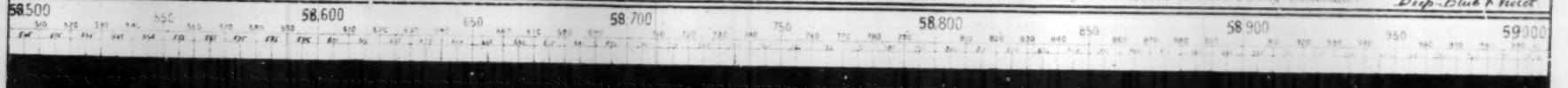
Deep-Blue. VOGEL'S SOLAR SPECTRUM 1880. PHOTOGRAPHIC AND PRISMATIC. *Deep Blue and Violet*



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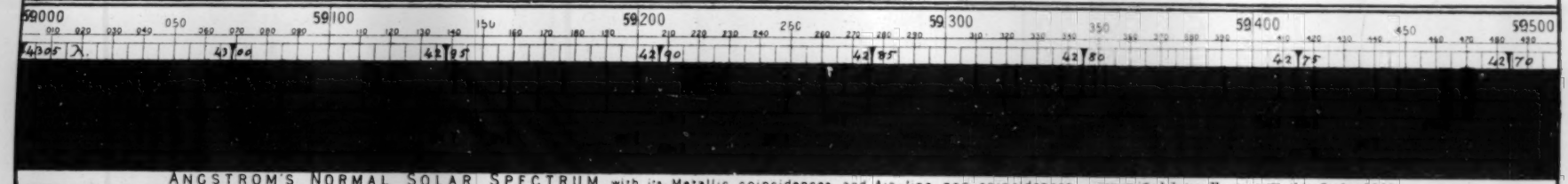
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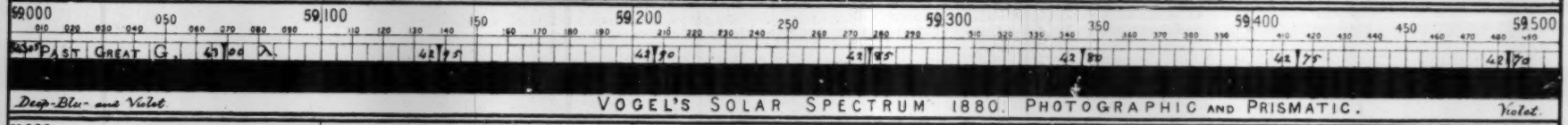


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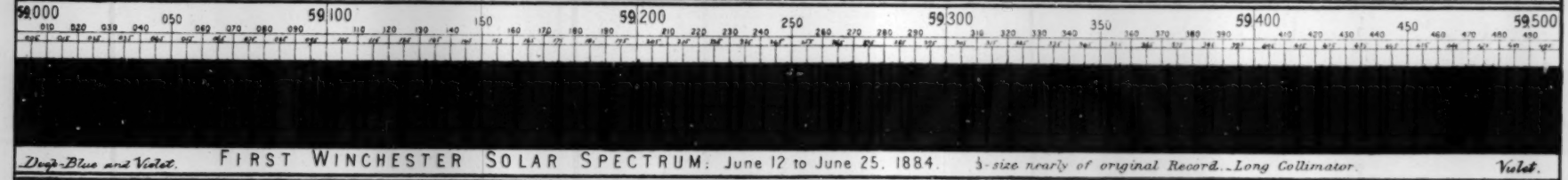
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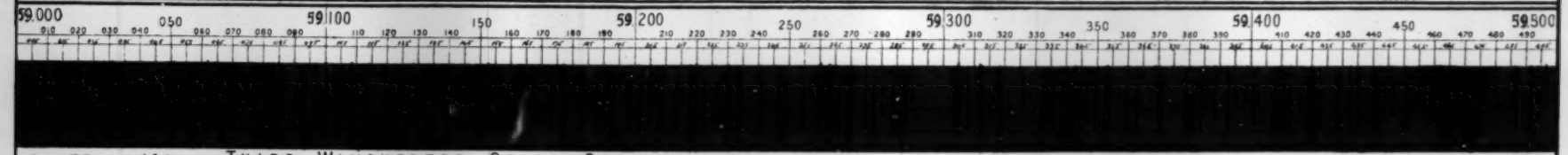
Deep-Blue and Violet. VOGEL'S SOLAR SPECTRUM 1880. PHOTOGRAPHIC AND PRISMATIC. *Violet.*



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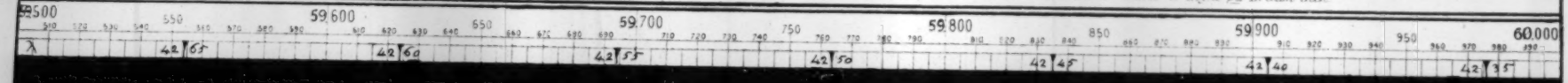
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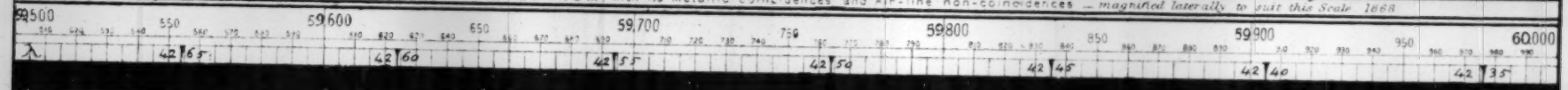


THE VISUAL SOLAR SPECTRUM IN 1884.

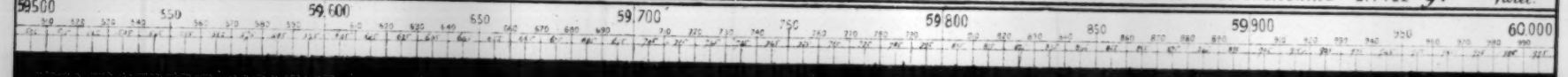
Illustrated by three separate Solar Spectra independently observed at Winchester in June and July with a Rowlands Grating Spectroscope, by C. Piazzi Smyth, F.R.S.E.
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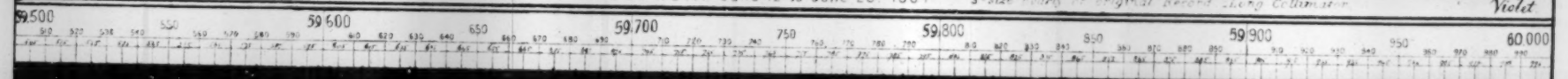
ANGSTROMS NORMAL SOLAR SPECTRUM, with its Metallic coincidences and Air-line non-coincidences — *magnified laterally to suit this Scale. 1868.*



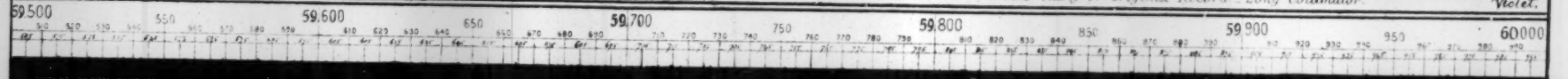
Violet. VOGEL'S SOLAR SPECTRUM 1880. PHOTOGRAPHIC. APPROACHING LITTLE *g*. Violet.



Violet. FIRST WINCHESTER SOLAR SPECTRUM. June 12 to June 25. 1884. *⅓-size nearly of original Record: Long Collimator.* Violet.



Violet. SECOND WINCHESTER SOLAR SPECTRUM. June 13 and 26 to 30. 1884. *⅓-size nearly of original Record: Long Collimator.* Violet.



Violet. THIRD WINCHESTER SOLAR SPECTRUM. July 3 to July 19. 1884. *⅓-size nearly of original Record: Short Collimator.* Violet.

GENERAL RULES FOR THE METHOD OF REPRESENTATION ADOPTED IN THE ABOVE SPECTRA

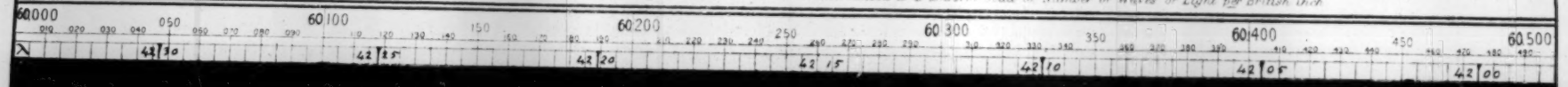
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3. Greater or less height or depth either of lines or of shaded bands, is intended to typify greater or less intensity of darkness and visibility of such lines or bands.
4. Cones of shade arranged on a vertical central axis indicate nebulous bands shaded off towards either side very gradually and delicately.


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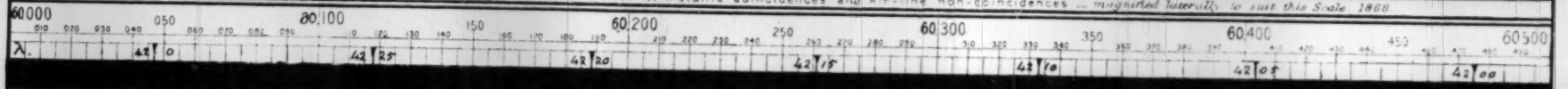
THE VISUAL SOLAR SPECTRUM IN 1884

Illustrated by three separate Solar Spectra independently observed at Winchester in June and July, with a Rowland's Grating Spectroscope, by C. Piazzi Smyth, F.R.S.E.

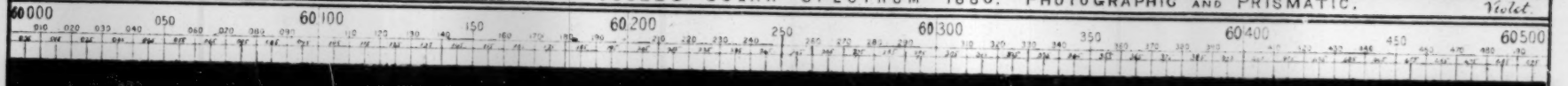
two references to older Solar Spectra by earlier observers being prefixed, and all of them reduced to a uniform Scale of Number of Waves of Light per British inch.



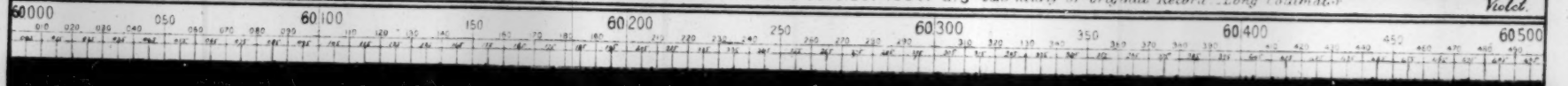
ANGSTROM'S NORMAL SOLAR SPECTRUM with its Metallic coincidences and Air-line non-coincidences ... *magnified laterally to suit this Scale. 1868.*



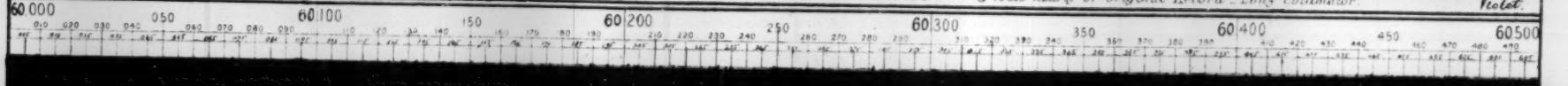
Violet. LITTLE "g". VOGEL'S SOLAR SPECTRUM 1880. PHOTOGRAPHIC AND PRISMATIC. Violet.



Violet FIRST WINCHESTER SOLAR SPECTRUM. June 12 to June 25. 1884. ... $\frac{1}{3}$-size nearly of original Record. Long Collimator. Violet.



Violet SECOND WINCHESTER SOLAR SPECTRUM. June 13 and 26 to 30. 1884. $\frac{1}{3}$-size nearly of original Record. Long Collimator. Violet.



Violet. THIRD WINCHESTER SOLAR SPECTRUM. July 3 to July 19. 1884. $\frac{1}{3}$-size nearly of original Record. Short Collimator. Violet.

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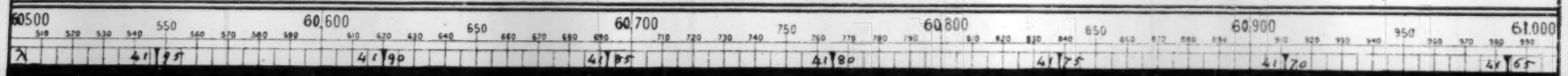
Printed 1884 by W. & A. K. Johnston, Edinburgh & London.

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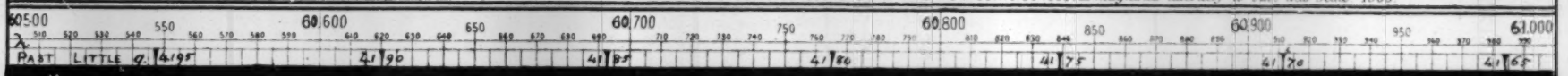
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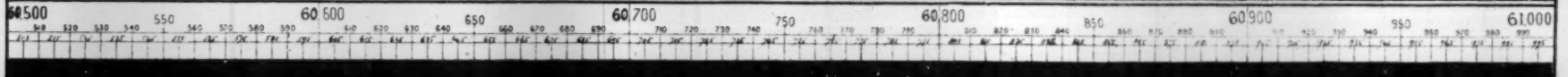
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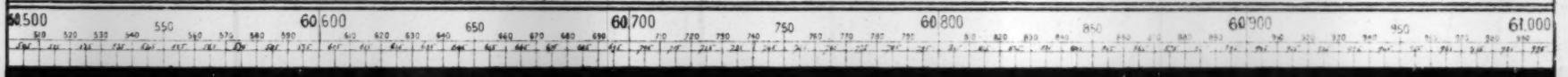
ANGSTROM'S NORMAL SOLAR SPECTRUM with its Metallic coincidences and Air-line non-coincidences — *magnified laterally to suit this Scale. 1868.*



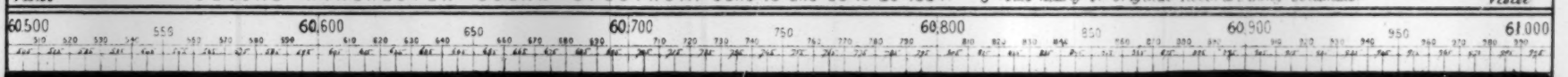
Violet. VOGEL'S SOLAR SPECTRUM. 1880. PHOTOGRAPHIC AND PRISMATIC. Violet.



Violet. FIRST WINCHESTER SOLAR SPECTRUM. June 12 to June 25. 1884. ⅓-size nearly of original Record. Long Collimator. Violet.



Violet. SECOND WINCHESTER SOLAR SPECTRUM. June 13 and 26 to 30 1884. ⅓-size nearly of original Record. Long Collimator. Violet.



Violet. THIRD WINCHESTER SOLAR SPECTRUM. July 3 to July 19. 1884. ⅓-size nearly of original Record. Short Collimator. Violet.

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Illustrated by three separate Solar Spectra independently observed at Winchester in June and July, with a Rowlands Grating Spectroscope by C. Piazzi Smyth, F.R.S.E.

For References to older Solar Spectra by earlier observers being prefixed, and all of them reduced to a uniform Scale of Number of Waves of Light per British inch.

61 000 | 61 100 | 61 200 | 61 300 | 61 400 | 61 500

λ. 41 60 | 41 55 | 41 50 | 41 45 | 41 40 | 41 35

ANGSTROM'S NORMAL SOLAR SPECTRUM with its Metallic coincidences and Atmospheric lines as magnified laterally to suit this Scale 1884

61 000 | 61 100 | 61 200 | 61 300 | 61 400 | 61 500

λ. 41 60 | 41 55 | 41 50 | 41 45 | 41 40 | 41 35

Violet

VOGEL'S SOLAR SPECTRUM 1880. PHOTOGRAPHIC AND PRISMATIC.

Violet and Lavender.

61 000 | 61 100 | 61 200 | 61 300 | 61 400 | 61 500

Violet

FIRST WINCHESTER SOLAR SPECTRUM June 12 to June 25 1884

½ size Scale of original Record. Long Collimator.

Violet and Lavender

61 000 | 61 100 | 61 200 | 61 300 | 61 400 | 61 500

Violet

SECOND WINCHESTER SOLAR SPECTRUM. June 13 and 25 to 30 1884

½ size nearly of original Record. Long Collimator.

Violet and Lavender

61 000 | 61 100 | 61 200 | 61 300 | 61 400 | 61 500

Violet

THIRD WINCHESTER SOLAR SPECTRUM. July 3 to July 19 1884

½ size nearly of original Record. Short Collimator.

Violet and Lavender

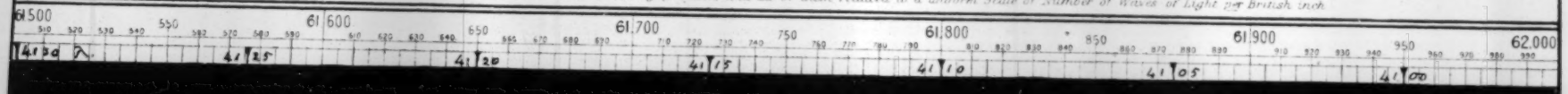
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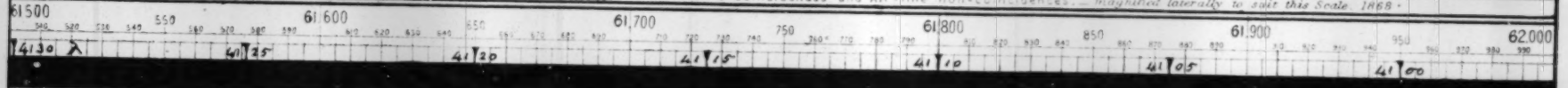


THE VISUAL SOLAR SPECTRUM IN 1884

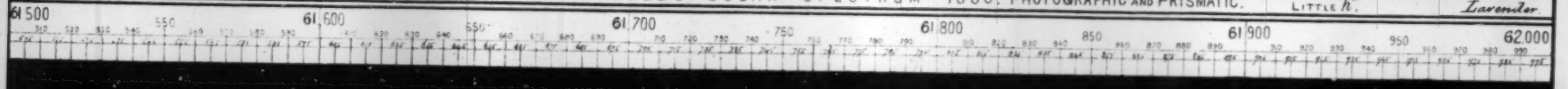
Illustrated by three separate Solar Spectra independently observed at Winchester in June and July, with a Rowland's Grating Spectroscope, by C. Piazzi Smyth, F.R.S.E.
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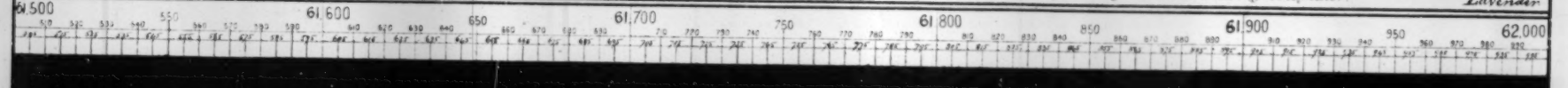
ANGSTROM'S NORMAL SOLAR SPECTRUM, with its Metallic coincidences and Air-line non-coincidences, — magnified laterally to suit this Scale. 1868.



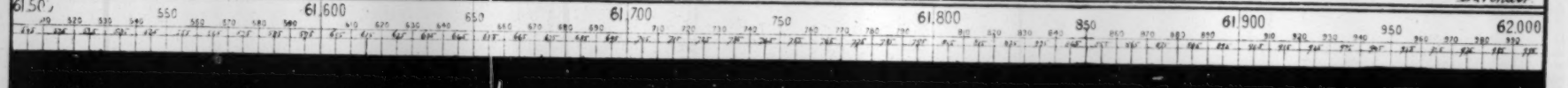
Violet and Lavender. VOGEL'S SOLAR SPECTRUM 1880. PHOTOGRAPHIC AND PRISMATIC. LITTLE *h*. Lavender



Violet and Lavender. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25. 1884 ½-size nearly of original Record. Long Collimator. Lavender



Violet and Lavender. SECOND WINCHESTER SOLAR SPECTRUM: June 13 and 26 to 30. 1884 ½-size nearly of original Record. Long Collimator. Lavender.



Violet and Lavender. THIRD WINCHESTER SOLAR SPECTRUM: July 3 to July 19. 1884 ½-size nearly of original Record. Short Collimator. Lavender.

GENERAL RULES FOR THE METHOD OF REPRESENTATION ADOPTED IN THE ABOVE SPECTRA

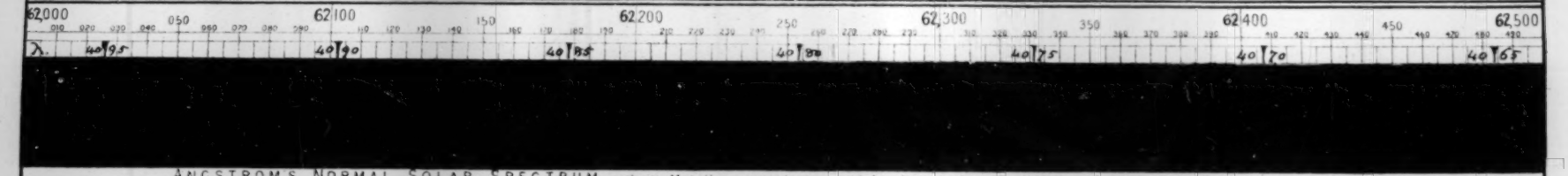
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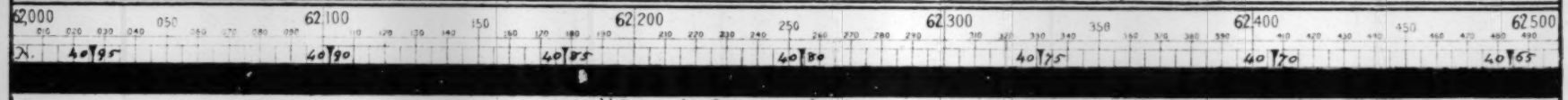
60

THE VISUAL SOLAR SPECTRUM IN 1884

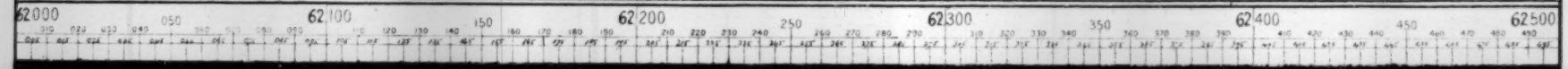
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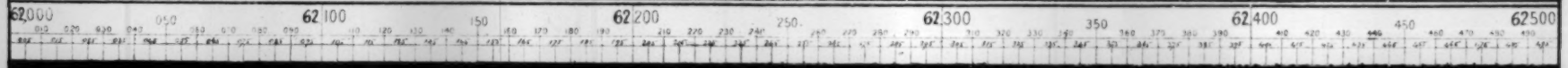
ANGSTROM'S NORMAL SOLAR SPECTRUM, with its Metallic coincidences and Air-line non-coincidences. *magnified laterally to suit this Scale 1884.*



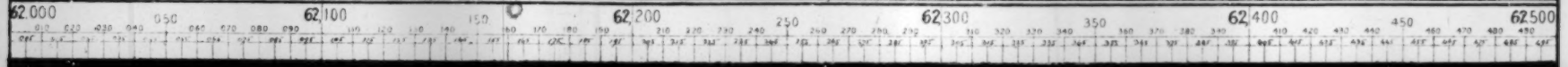
Lavender. VOGEL'S SOLAR SPECTRUM 1880. PHOTOGRAPHIC AND PRISMATIC. Lavender



Lavender. FIRST WINCHESTER SOLAR SPECTRUM June 12 to June 25, 1884. $\frac{1}{3}$-size nearly of original Record. Long Collimator. Lavender



Lavender. SECOND WINCHESTER SOLAR SPECTRUM. June 13 and 26 to 30, 1884. $\frac{1}{3}$ size nearly of original Record. Long Collimator. Lavender



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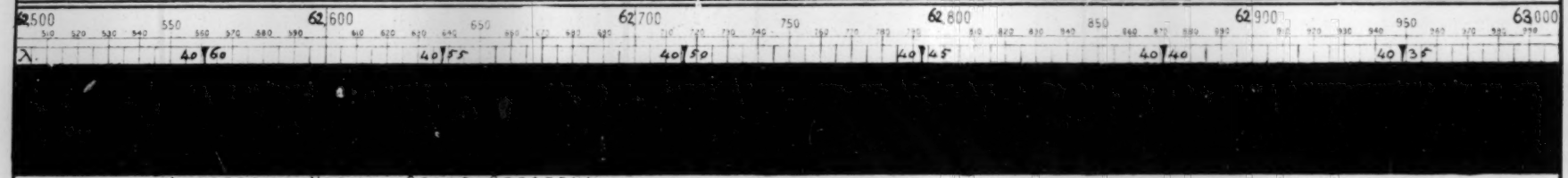
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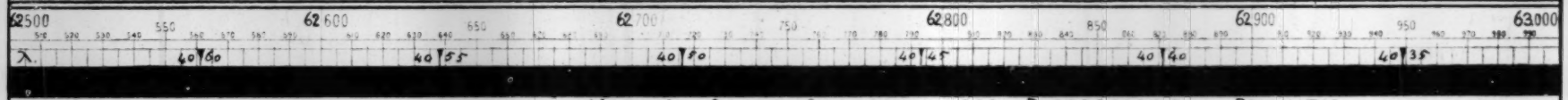


THE VISUAL SOLAR SPECTRUM IN 1884

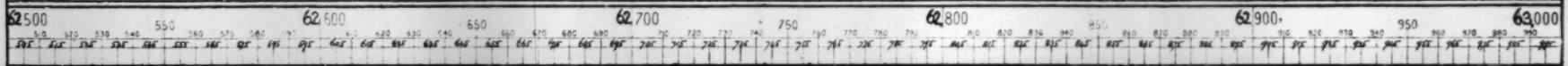
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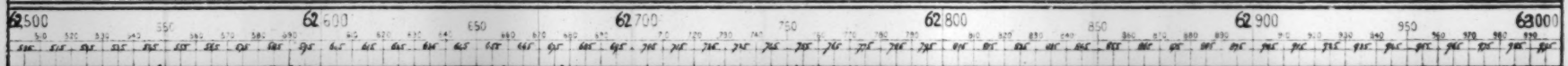
ANGSTROM'S NORMAL SOLAR SPECTRUM, with its Metallic coincidences and Air-line non-coincidences — *magnified vertically to suit this Scale 1868*



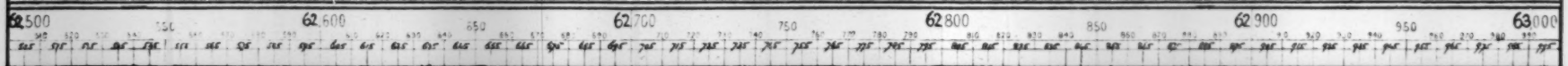
Lavender. VOGEL'S SOLAR SPECTRUM 1880. PHOTOGRAPHIC AND PRISMATIC. Lavender.



Lavender. FIRST WINCHESTER SOLAR SPECTRUM: June 12 to June 25, 1884 ⅓-size nearly of original Record. Long Collimator. Lavender.



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Lavender. THIRD WINCHESTER SOLAR SPECTRUM: July 3 to July 19, 1884 ⅓-size nearly of original Record. Short Collimator. Lavender.

GENERAL RULES FOR THE METHOD OF REPRESENTATION ADOPTED IN THE ABOVE SPECTRA

1. A [illegible] and the [illegible] and [illegible] spectroscope [illegible] of the Sun [illegible] of the slit and to nothing else under the Sun [illegible]
2. [illegible] [illegible] [illegible]

BRITISH
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MUSEUM

XXX.—*Observations on the Recent Calcareous Formations of the Solomon Group made during* 1882–84. By H. B. Guppy, M.B., F.G.S., Surgeon H.M.S. "Lark." Communicated by John Murray, Esq. (Plates CXLIV., CXLV.)

(Read 15th June 1885.)

Preliminary Remarks.

On account of the treacherous character of the natives of the Solomon Group, no extensive geological observations have ever been made in these islands since the period of their discovery by the Spaniards three centuries ago. For this reason my excursions in these regions were not free from personal risks; in many places they were considerably curtailed, and in some places they had to be abandoned altogether. Fortunately, however, I was able to make a detailed examination of several of the smaller islands, the natives of which had been first conciliated by the kindly tact of Lieut.-Commander C. F. Oldham, to whom I am indebted for much assistance in my pursuits. But from the circumstances in which I was placed, both on board and on shore, it was necessary, in order to accomplish much, to dare a little.

This archipelago includes seven or eight large islands, some of which are from 70 to 80 miles in length, and the highest from 8000 to 10,000 feet in height. Besides these, there are a great number of smaller islands and islets, some of volcanic and others of recent calcareous formations. Restricting my remarks to those islands which are wholly or in part composed of these calcareous rocks, I may observe that, although only able to become acquainted with a small portion of the Solomon Group, the islands which I examined represent the different types of islands that there exist. The larger islands, composed in mass of ancient volcanic rocks flanked on the lower slopes of their sea-borders by more recent calcareous formations, are represented by St Christoval. Among the smaller islands, the following types occur:—in the first place, there are those which are made up in bulk of a soft Foraminiferous deposit encrusted only by coral limestone, as in the island of Ugi. Then there are those which are composed in great part of these soft deposits and coral limestones, but partly also of volcanic rocks, as in the Shortland Islands. In the next place, there are islands, usually small and of no great height, which are entirely of coral rock, as in the case of Stirling Island. Santa Anna represents probably an uncommon type of island, being an upraised atoll with its foundations

exposed. The numerous islets formed on the coral reefs at the present sea-level do not come within the province of this paper.*

The methods employed by Mr MURRAY in the examination of these recent rocks are similar to those which he employed in examining the deep-sea deposits obtained in the "Challenger" and other Expeditions. The *Carbonate of Calcium* was determined by estimating the carbonic acid, weak and cold hydrochloric acid being used for this purpose. The part insoluble in the acid is designated "*Residue*," which by washing and decantation is separated, on account of the different densities of its constituents, into three parts—(*a*) *Minerals*, the contraction *m. di.* indicating their mean diameter in millimetres; (*b*) *Siliceous Organisms*, including also the glauconitic casts of Foraminifera and of other calcareous organisms; (*c*) *Fine Washings*, including those particles which, resting in suspension, pass with the first decantation. The numbers in brackets indicate the percentage in the whole deposit.† In addition to the foregoing method, sections of many of the rocks were employed in their examination.

THE ISLAND OF UGI.

The island of Ugi, which is six miles in length and between two and two and a half miles in breadth, rises to an elevation of about 500 feet above the sea. From some points of view it has the profile of a broad-brimmed hat, due to a pause in the elevating movement when the land was 200 feet lower than it is at present; but more commonly, losing its hat-shape, it appears as a level-topped island rising gently from the sea. Fringing reefs skirt the greater portion of its coast.

Its geological structure may be briefly described as composed in mass of a soft earthy bedded deposit, resembling the "volcanic muds" of the "Challenger" soundings, containing numerous Foraminifera, and encrusted near the coast by coral limestone which almost disappears in the higher regions.

The Coral Limestone.—Referring for a moment to the low-lying sea border of this island, which, elevated between 2 and 8 feet above the sea, is composed of calcareous sand, shells, and coral débris imperfectly mixed with soil, I pass on to the description of the coral limestone crust. This rock is occasionally exposed at the coast in cliffs not exceeding 16 or 18 feet high. In the northern part of the island I found an eminence of this coral rock rising

* In the examination of these calcareous rocks, as well as in the preparation of this paper, I have been assisted by Mr JOHN MURRAY, to whom, as well as to the ABBÉ RENARD, I have to express my indebtedness. I also desire to express my thanks to Mr MURRAY'S assistants in the "Challenger" Office, Mr FRED PEARCEY and Mr JAMES CHUMLEY.

† For further information on this subject *vide* a paper on "The Nomenclature, Origin, and Distribution of Deep-Sea Deposits," by JOHN MURRAY and A. RENARD, in the *Proceedings of the Royal Society of Edinburgh*, 1883-1884, pp. 504-506.

to between 90 and 100 feet above the low-lying land at its base, and removed inland a few hundred yards from the coast. Its interior has been excavated into a suite of caverns known as the Waupa Caves. This was the greatest thickness of coral rock that I saw exposed in the island of Ugi; and I doubt if it anywhere much exceeds a hundred feet. As one ascends the slopes of the island this formation thins away, and only occasional fragments occur in the red argillaceous soil. The greatest elevation at which I found the coral rock was about 425 feet above the sea.

The Soft Foraminiferous Deposit.—This rock, which is exposed in the ravines and gorges excavated by the streams, forms the mass of the island. Closely resembling the prevailing formation of Treasury Island, described in another portion of this paper, it presents itself in the fresh condition as a chocolate-coloured argillaceous and somewhat friable deposit, in which Foraminiferous tests may be usually observed. It is often stained reddish-brown near the surface through the hydration of its iron oxides. Specimens of this rock, after being kept some time, become more friable and of a lighter colour. Subjoined I have given the characters of this deposit with the list of the Foraminifera, as determined by Mr MURRAY:—

A friable rock of a greenish-blue colour showing minute organisms imbedded. Its characters are those of the "volcanic muds" found in the "Challenger" Expedition around volcanic islands. It seems to have been formed in comparatively shallow water, although not sufficiently near to the surface to permit the reef corals to grow.

Carbonate of Calcium (13·93 per cent.) consists of Coccoliths, Rhabdoliths, Gasteropod and Lamellibranchiate shells, Echinoderm fragments, calcareous Algæ, and many pelagic and bottom forms of Foraminifera, (*vide* List).

Residue (86·07) of a slate colour, consists of—

(*a*) *Minerals* (50·00) m. di. 0·3 mm. a few larger; felspar, magnetite (abundant), hornblende, augite; many fragments of volcanic rocks with pumice and glassy materials.

(*b*) *Siliceous Organisms* (1·00); a few Sponge spicules.

(*c*) *Fine Washings* (35·07), argillaceous matter, and many fine mineral particles.

List of Foraminifera.

Planispirina celata (few).
Bolivina costata (rare).
Textularia quadrilatera (rare).
Bulimina sp. (many).
Sagrina columellaris (common).
„ striata (common).
„ virgula (common).
Uvigerina asperula (few).
Globigerina bulloides (rare).
„ „ *var.* triloba (common).
Globigerina rubra (common).
„ dubia (few).
„ inflata (few).
„ conglobata (few).
Sphæroidina dehiscens (few).
Pullenia obliquiloculata (few).
Pulvinulina menardii (many).
„ „ *var.* tumida (many).
Nonionina umbilicatula (rare).
Polystomella craticulata (rare).

Additional List (relative frequency not ascertained).

Cassidulina crassa.
Bulimina marginata.
Uvigerina pygmæa.
Nodosaria soluta.
Globigerina sacculifera.
Pulvinulina elegans.
„ canariensis.
„ menardii *var.* fimbriata.
„ repanda.
Truncatulina sp.

This formation displays regular bedding, the beds being in some localities separated by thin bands, one to two inches thick, of a loose coarser-grained deposit of the same nature.* Having explored most of the principal streams, which are mostly confined to the west side of the island, I have shown the main results in the accompanying plan of Ugi (Plate CXLIV. fig. 1); whilst the ideal section (Plate CXLIV. fig. 2), which actually represents a section through the south portion of the island, will serve to illustrate the structural features, more particularly the curvature of the beds and the comparative thinness of the crust of coral rock. The tortuosity of the streams, with other circumstances, combined to hinder my efforts to arrive at a satisfactory explanation of the lie of the beds; and it was only after repeated tedious examinations of these stream-courses that I was able to reduce my observations to order. The dip varies usually between 10° and 15°, but it may rise to as much as 35°. In the higher parts of the island, near the sources of the streams, the beds are generally horizontal or very gently inclined. By referring to the plan of the island, where the arrows indicate the direction of the dip, it will be seen that the prevailing trend of the folds is N.E. to S.W.; but in the northern part of the island they run more N.W. to S.E. Although the series of curves into which these beds have been thrown are generally regular, yet the occasional sudden increase of the dip and the occurrence of local contortions are circumstances which afford evidence of the minor disturbances to which these beds have been subjected. The natural sections displayed in the sides of the ravines and gorges vary considerably in different streams, and in different parts of the same stream; most frequently, however, the stream appeared to have run along the crest of an anticlinal ridge. I should here allude to a common feature of these stream-courses, as well as of those of Treasury Island, viz., the extensive deposits of calcareous tufa which frequently encrust the sides of the gorges and constitute a series of step-like terraces over which the water flows in the higher parts of some of the streams; leaves, twigs, and shells are often thus imbedded.

I carefully searched these beds for enclosed organic remains in addition to the minute organisms there imbedded. Entire shells are rarely found, those referred to in the description of the composition of these rocks being the fine fragments of Lamellibranchiate and Gasteropod shells. I only came upon five

* In a limited locality in the south part of the island the rock was a very fine grained calcareous tuffa, containing a few siliceous marine organisms.

specimens of a small bivalve, which from its delicacy was often difficult to obtain in anything like a perfect condition. Dark patches, where the Foraminiferous tests occur in increased numbers, stain these deposits; and there are imbedded numerous small rounded masses of a concretionary nature, containing much peroxide of iron and a little peroxide of manganese. The upper surfaces of these beds are frequently marked by cracks, which have been filled with a material that projects above the surface of the rock on account of its greater durability; but from the moist and semi-consolidated state of the rock, these shrinkage-cracks must be viewed as of modern origin.

It is noteworthy that I did not find any volcanic rock *in situ* in this island.

In concluding my description of Ugi, I may refer to the pauses in the movement of upheaval which have left their marks behind them. On the north-west coast, I found in the faces of the cliffs of a small sheltered cove two lines of ancient erosion, the lower indicating an elevation of 4½ to 5 feet as the most recent change in level, and the upper line indicating a previous upheaval of 6 to 7 feet. In the interior there is evidence of a long pause in the elevatory movement, when the island was about 200 feet lower than it is at present, which, as already stated, has given Ugi from some points of view the profile of a broad-brimmed hat. In the quiet waters of Selwyn Bay on the west coast, we find testimony of an upheaval still in progress. Reefs have been elevated in mass so that points of coral rock project between 1 and 2 feet above the high-water level. Mr Stephens, a resident trader at Selwyn Bay, tells me that during the past eight years the greater projection of these points of the reef has been a matter of observation to him; and that within that period the high-tide mark has receded between 12 and 15 feet, so that some cocoa-nut palms, which eight years since were within reach of the waves at high-water, are now only reached by the spray.

In the description of Treasury (page 555), I have referred to the two most recent lines of ancient erosion as corresponding with the two most recent upheavals of Ugi. In both islands there is evidence of a recent upheaval of about 5 feet, and of anterior upheaval of about 6 or 7 feet. Such coincidences in two islands situated towards opposite ends of the group, and lying about 400 miles apart, would appear to indicate the general character of the movement of elevation in the whole of the Solomon group.

The Island of Treasury.

The island of Treasury is of an oval shape, with a breadth of 5½ miles, a length of 9 miles, and an elevation of 1150 feet above the sea. Viewed from

seaward, this island has a rounded profile, in this respect resembling the island of Ugi at the opposite end of the group, which has a somewhat similar geological structure. Its bold sea cliffs and the narrow ravines worn by the streams in the interior afford favourable opportunities of examining its geology; and it may be briefly described as composed in mass of a soft bedded Foraminiferous deposit, resembling the "volcanic muds" of the "Challenger" soundings, which is covered over by a crust of coral limestone that only attains any thickness near the coast, and is wanting altogether in the higher interior regions of the island. Its structure, however, is not so simple as that of its counterpart, Ugi Island, there being a greater variety in the characters of the softer deposit and of the harder coral limestone, while the nucleus of volcanic rock, around which these calcareous muds and coral rocks were formed, is here partially exposed. A casual observer by the ascent of a single stream would obtain a very imperfect, if not an erroneous, impression of the structure of this island; if he did not extend his field of observation beyond the beach, where the village of Saveki lies, he might carry away with him the impression that Treasury was of volcanic formation, an error into which he would not have been the first to fall. It was only by a laborious examination of nearly all the larger stream-courses and by numerous ascents to the summit from different sides of the island that I was enabled to form a true conception of its structure.

The Coral Limestone.—Having in another portion of this paper referred to the different kinds of coral limestones, so called, it will suffice for me to state here that I shall always employ this term as applying to a hard usually compact unstratified limestone in which the massive corals may be observed imbedded or which on examination exhibits coral structures.* A wide ledge of this coral rock, rising from about 50 feet above the sea near the coast to rather over 100 feet further inland, forms the sea-border around the greater portion of the circumference of this island. This ledge is covered by a reddish clayey soil, through which protrude occasionally large fragments of the massive corals. Up the hill-slopes the coral limestone may be traced on the surface as high as 300 to 400 feet above the sea; and fragments of the reef corals may be observed at heights varying between 150 and 200 feet. At elevations exceeding 300 or 400 feet above the sea, the coral rock usually disappears from the surface, or it may be only observed as small masses. However, in the same hill I found at a height of 675 feet an ancient reef-mass of true coral rock, running like a wall about 10 feet high for some nine or ten paces along the hill-slope; and at a height of 900 feet I came upon a small block of a *Porites* in a rotten condition. The average thickness of the coral rock at or near the coast where it is displayed

* Very frequently corals play only a secondary part in the building up of the rock which is largely composed of calcareous Algæ, fragments of Echinoderms and Molluscan shells.

in greatest mass, probably varies between 70 and 100 feet. At the sea-border, where it is exposed in a line of high inaccessible cliffs, it is riven into chasms and deep fissures by the action of the surf.

I should here refer to Stirling Island lying off the south coast of Treasury Island, and enclosing the harbour (*vide* Plate CXLIV. fig. 3). It is entirely of coral limestone, the islets in the harbour being of the same formation. Its general surface is level, with an average height of 40 to 50 feet, and a maximum height of 70 feet. In the bold cliffs, which form the weather coast of this island, there are numerous imbedded masses of the reef-building corals, many of them measuring 4 feet across, the majority of them in the position of growth,* but some of them inverted. It is worthy of notice that the large astræid and brain corals imbedded in the upper portion of the cliff-face were only half the size of those imbedded some 15 or 20 feet below.

The Soft Foraminiferous Deposit.—This rock, of which the mass of the island is composed, has very much the composition of the "volcanic muds" which were found during the "Challenger" Expedition in the vicinity of volcanic islands. It is usually soft and friable, and when unaffected by the hydration of its iron oxides is of a bluish-grey colour. It displays a regular stratification, and, as will be seen in the plan of the island appended where the arrows along the courses of the streams indicate the direction of the dip, the amount of inclination varies between 10° and 30°.† To the naked eye it usually presents no other conspicuous organic remains than the white specks of the more minute Foraminiferous tests and the larger macroscopic tests of such species as *Cristellaria calcar*, *C. mamilligera*, and others. A description of such a specimen is here appended :—

A friable rock, of a bluish-grey colour, showing minute organisms imbedded.

Carbonate of Calcium (7·74 per cent., the amount varying in different specimens between 5 and 25 per cent.) consists of Coccoliths; a few *Globigerina bulloides* var. *triloba*, a few *Globigerina conglobata*, and other Foraminifera, and fragments of Echinoderms. (*Vide* below for further list of the Foraminifera.)

Residue (92·26) slate colour, consists of—

(*a*) *Minerals* (60·00) m. di. 0·8 mm.; some fragments 1·0 to 2·0 mm.; felspar, magnetite, augite, hornblende, fragments of pumice, scoriæ, and other volcanic rocks, with many glassy fragments.

(*b*) *Siliceous Organisms*, none noticed.

* I paid especial attention to the position of the imbedded corals, and only found two inverted. The large shells of *Tridacna gigas* are also enclosed in the rock in the usual position occupied during the life of the mollusc.

† The general dip would appear to be away from the elevated interior of the island.

(*c*) *Fine Washings* (32·26), argillaceous matter and many fine mineral particles.

List of the Foraminifera contained in a Specimen of the Soft Foraminiferous Rock above described.

Miliolina oblonga (rare).
Textularia turris (few).
„ concava (few).
Gaudryina rugosa (few).
Clavulina communis (few).
Vaginulina bruckenthali (rare).
Bolivina punctata (many).
„ hanktkeniana (many).
„ subangularis (few).
Bulimina inflata (rare).
„ affinis (many).
Nodosaria filiformis (rare).
Frondicularia inæqualis (rare).
„ interrupta (rare).
Cristellaria articulata (rare).
„ crassa (several).
„ calcar (several).
„ latifrons (several).
„ aculeata (several).
Uvigerina pygmæa (rare).
„ schwageri (many).
Sagrina columellaris (many).
„ virgula (many).
„ striata (many).
Truncatulina lobatula (many).
„ rostrata (very common).
„ haidingeii (few).
Globigerina bulloides (many).
„ „ *var.* triloba (common).
„ rubra (many).
„ dubia (few).
„ æquilateralis (few).
„ (orbulina) universa (few).
Pullenia sphæroides (rare).
Planorbulina larvata (rare).
Pulvinulina menardii (many).
„ repanda (few).
„ elegans (few).
Rotalia soldanii (few).
Amphistegina lessonii (rare).
Nonionina umbilicatula (rare).

In some localities this deposit becomes highly fossiliferous, when it generally assumes the character of a compact mottled grey limestone, and displays to the eye fragments of corals with Pteropod and Lamellibranchiate shells, &c. Interbedded with the softer rock, and offering a greater resistance to the action of water, its position is often marked by waterfalls in the stream-courses; but it is absent from the higher parts of the streams and from the central districts of the island. The following are the characters of this harder rock:—

A compact fossiliferous limestone, containing a good deal of volcanic débris, and probably formed in shallower water than the friable rock just described.

Carbonate of Calcium.—About 60 per cent., consists of fragments of Lamellibranchiate shells, coral, calcareous Algæ; and the following Foraminifera:—*Carpenteria*, *Globigerina bulloides*, *Polytrema rubra*, *Truncatulina*, *Lagena*, *Nummulina*, and *Cristellaria*.

Residue, 40 per cent., consists of—

(*a*) *Minerals* (15 per cent.), felspar, magnetite, augite, hornblende, and glassy fragments.

(*b*) *Siliceous Organisms*, none noticed.

(*c*) *Fine Washings* (25 per cent.), consisting of argillaceous matter and fine mineral particles.

The softer friable deposit is alone found in the elevated interior of the island, where it is exposed in a line of inland cliffs 300 feet in height, lying

near the centre of the island and entirely composed of this formation. This was the greatest thickness that I saw exposed of this soft Foraminiferal deposit; and since this line of cliffs represented a natural section of the summit, I may safely conclude that the elevated interior of the island is entirely of this formation, a *conclusion* which is supported by the existence of other sections almost as extensive in that region, and one which has an important bearing on the past history of Treasury Island. The beds in this line of inland cliffs dip westward 12° to 15°; the vertical faces of the cliff being preserved by the scaling off of large slabs of rock along the lines of joint which correspond with the strike of the beds.* On the level summit, wherever a small rivulet exists, this soft Foraminiferous deposit is exposed. I now append the description of specimens of this rock obtained from the inland cliffs above referred to.

A very friable rock, of a greenish-grey colour, containing from 3 to 10 per cent. of carbonate of lime, which consists of a few Coccoliths, and the following Foraminifera:—*Cassidulina crassa* (rare), *Uvigerina asperula* (few), *Truncatulina lobatula* (rare), *Rotalia soldanii* (rare), *Pulvinulina elegans* (rare), and fragments of *Globigerinæ*.

Minerals, about 60 per cent., consisting of mica, quartz, magnetite, hornblende, augite, felspars, many glassy fragments, scoriæ, and green fragments—glauconite?

Fine Washings, about 30 per cent., consisting of argillaceous matter, fine mineral particles, glassy fragments, and fragments of scoriæ.

Note.—This rock seems to have been formed in comparatively shallow water, as it is made up chiefly of the débris of volcanic rocks washed down from the land, and afterwards mixed with the remains of minute organisms which live near the coast.

Deposits yet more recent than those which compose the mass of the island, I found exposed in the banks of the lower parts of the streams opening on the south coast. Here is displayed a bluish calcareous loam-rock containing Foraminifera and numerous Molluscan shells. The following are its characters:—

A very friable rock.

Carbonate of Calcium (6·52 per cent.), consists of a few Coccoliths; fragments of Echinoderm, Lamellibranchiate, Pteropod, and Ostracode shells; a few Alcyonium spicules; and some Foraminifera (*vide* List).

Residue (93·48 per cent.), greenish-brown in colour, consists of—

(*a*) *Minerals* (50·00) m. di. 0·3 mm. A great quantity of magnetite,

* At the foot of these cliffs a rich red ochre-clay has accumulated, probably as washings from the cliffs above. It contains only 15 to 20 per cent. of mineral particles, and exhibits but a very slight effervescence with dilute acid.

felspar, hornblende, augite, many glassy fragments, and fragments of black organic matter.

(*b*) *Siliceous Organisms* (2·00), a few glauconitic-like casts.

(*c*) *Fine Washings* (41·48), argillaceous matter, fine mineral particles, many glassy fragments, and a greenish organic-like matter.

Foraminifera.—*Globigerina bulloides*, and var. *triloba*; *G.* (*Orbulina*) *universa*, *G. dubia*, *G. æquilateralis*, *Pulvinulina menardii* and *P. elegans*, *Sagrina*, *Bolivina*, *Nonionina*, *Polystomella*, and *Biloculina*. All these Foraminifera are in a dwarfed stage.

Molluscs.—*Nassa*, *Cylichna*, *Tellen*, and another bivalve (in numbers), also *Conus*, *Natica*, *Turritella*, *Melania*, *Monodonta*, *Dentalium*, *Bulla*, *Leda*, *Arca*, &c.: Pteropods represented by *Creseis* (in numbers), and *Hyalæa* (a few).

Echinoderms.—A species, probably of *Spatangus*, in numbers.

Miscellaneous.—Partially carbonised stems of plants; fragments of branching corals and volcanic rocks, 2 to 3 inches in diameter and under. Frequently penetrated by small tubular cavities, filled with coarse sand and minute shells, being the burrows probably of some annelid or crustacean.

This deposit displays a rudely laminated structure, the layers between 1 and 3 inches in thickness being steeply inclined 70° towards the coast. It forms the level ground on which the village of Saveki stands, removed 10 to 20 feet above the beach; and may be shortly described as formed from the washings of Treasury Island previous to its last upheaval. A very similar deposit is now in process of formation in the deeper parts of the harbour in depths below the coral zone, evidently derived in great part from the large amount of sediment brought down by the streams during the rains. Probably the above loam-rock was formed in a similar manner and at similar depths (20 to 50 fathoms), and the dwarfed condition of its Foraminifera may be attributed to the injurious effect of the fresh-water of the streams.

Hard Foraminiferal Limestone.—I have included under this name rocks which occupy the position of the coral limestone at the surface, but to which the term of coral rock is scarcely applicable. They are usually hard, compact, and of a yellowish-brown colour, and are largely composed of Foraminifera. In Treasury Island, as in the Shortland Islands, they are not unfrequently found on the crest of hills, but I never observed them at a greater elevation than 750 feet above the sea. Further information on the characters of these rocks is given in the portion of this paper devoted to the consideration of the coral limestones, so called (*vide* pages 564 and 575).

The Nucleus of Volcanic Rock.—I referred above to the partial exposure of the nucleus of volcanic rock around and over which have been formed the Foraminiferous muds and overlying coral-reef formations that have been described in detail. The only locality where the volcanic rock is exposed to

view is near the south side of the island. The large stream that opens into the harbour close to the village of Saveki, cuts through, at a distance of some 300 yards in a straight line from the coast, an amygdaloidal dolerite. This rock, which is here exposed in mass, is often porphyritic in structure. Up the adjoining slope of the hill-spur on the right side of the stream, fragments of this and other volcanic rocks may be found on the surface. At the height of 300 feet it is exposed *in situ;* and at intervals on the hill slopes above small fragments of volcanic rocks of somewhat varying characters* may be observed, even up to 900 feet above the sea. I have little doubt therefore but that the mass of the spur, overlooking the village of Saveki on the west, is of volcanic formation, being merely encrusted by the recent Foraminiferous muds and coral rocks.

History of the Formation of the Island.—By a reference to the section of Treasury Island (Pl. CXLIV. fig. 4), its structural history will be readily understood. An ancient submerged volcanic peak, having been covered by a thickness of several hundred feet of deposits, for the most part resembling the muds now being formed around oceanic volcanic islands, has finally been encrusted with coral reefs and been elevated above the sea to a height of nearly 1200 feet. How far beneath the surface of the sea this volcanic peak may have been originally submerged, it is difficult to say. But as bearing on this question I may here quote from Mr MURRAY's description of a hard Foraminiferal limestone, which was found at the surface. "The organisms in this rock, as well as the minerals, are," he writes, "similar to those found in deposits of modern seas in depths from 500 to 800 fathoms, near volcanic islands." The class of hard Foraminiferal limestones has already been referred to in connection with Treasury Island (p. 554).

That there have been pauses in the elevatory movement, there can be no doubt; but only the latest have left their marks behind at the present day. Thus, the broad ledge of coral rock which forms the sea-border was the work of a lengthened interval, since which there has been an upheaval of from 50 to 100 feet. At that time (*vide* Plan and Section Pl. CXLIV. figs. 3 and 4) Stirling Island appeared at the surface as a line of barrier-reef off the weather coast of Treasury Island, from which it was separated by a deep lagoon-channel between 50 and 60 fathoms in depth—the present harbour. The islets of coral rock, that lie inside Stirling Island, may possibly mark the position of other volcanic peaks. We have, however, in the coasts of the harbour and in the cliffs of Stirling Island, evidence preserved of yet more recent pauses in the elevation. An old sea-level is indicated in several places, since which there has been an upheaval of some 10 or 12 feet. But the most modern upheaval is shown in the margin of recently elevated and often well-preserved corals,

* Augite-andesite and porphyritic felsite, &c.

exposed about a foot at high tide, which fringes the shores of the harbour. Allowing for the rise and fall of the tide in this region, I estimate this most recent elevation at not less than 5 feet. It is of importance to note, as indicating the coincidences in the elevatory movements in this region of the Pacific, that in the islands of Ugi and Santa Anna, which lie over 400 miles distant at the opposite end of the Solomon group, there have been modern upheavals of the same limited extent (*vide* page 549).

The first page in the history of Treasury Island, as an island, began when the submarine volcanic peak had been brought up to within the depths at which reef corals thrive, by the constant piling up of sediment assisted by the upheaving movements. During these movements, the barrier-reef, now represented by Stirling Island, was formed by the outward growth of the reef. Coral reefs, however, have played but a secondary part in the actual building up of the island of Treasury as a whole.

The Island of Santa Anna.

The small island of Santa Anna, at the eastern extremity of the Solomon group, presents an example of a raised atoll. Having a nearly circular form with a length and breadth of $2\frac{1}{2}$ and 2 miles respectively, this island consists of a central basin surrounded by an elevated rim which is wanting at the middle of the west or lee side. The bottom of the basin, which extends downwards to about 100 feet below the sea-level, is occupied by two fresh-water lakes (*vide* Plan and Section of this island Plate CXLIV. figs. 5 and 6).

The elevated rim has a broad level summit, varying between a quarter and one-third of a mile in width, and elevated 200 feet above the sea, except on the south and south-west sides of the island, where it has only half this elevation. From the middle of this raised margin, on the east or weather side, there rises an elevated mass to a height of about 470 feet above the sea, which gives to the island, when viewed either from the eastward or the westward, a profile resembling a broad-brimmed low-crowned hat. On the flat summit of this elevated mass, there is a basin-shaped hollow between 100 and 150 yards across and 35 or 40 feet in depth (*vide* Section Plate CXLIV. fig. 5).

The central depression may be described as a somewhat symmetrically shaped hollow, the bottom of which, lying about 100 feet below the sea-level, is occupied by two fresh-water lakes, the waters of which are not affected by the rise and fall of the tide, although lying at or about the mean tide-level. The interior of this island is, in fact, a closed basin, which is completely cut off from the sea; and it may be aptly compared to a bowl of fresh water floating on sea water. But so low is the barrier that shuts out the waters of the ocean—a barrier which is composed for the most part of coral detritus, calcareous sand, and shells—that a depression of about 25 feet would admit the sea into the

lakes, and a continuation of the downward movement to the same extent would transform the interior of the island into a large salt-water lagoon. In my traverses across this basin-shaped interior I found evidences of the sea having very recently occupied its lower levels. In the marshy ground in the vicinity of the lakes I occasionally came upon the coral rock exposed in flat surfaces resembling those of the ordinary reef-flat, whilst in the drier regions the soil was mixed with calcareous sand and shell "débris;" and numbers of sea shells, of ancient appearance from prolonged exposure, lay on the surface or were buried an inch or two beneath the soil. Many of these shells, belonging to the Ostræidæ, Cardiadæ, Neritidæ, &c., were encrusted on their inner surfaces by a dried calcareous mud. On opening one bivalve shell, with the two valves in apposition, the ligament having decayed, I found its interior to a great extent filled by this dried calcareous mud, which, from the impression that it retained of the soft parts of the Mollusc, afforded proof that the shell-cavity had become filled with this material before decomposition had set in.

The lakes, I should have added, do not occupy the centre of the basin but lie towards the western side of the island, the centre being marked by an eminence of coral limestone, the level summit of which is elevated about 160 feet above the sea. In concluding my description of the interior of this island, I will refer to the basin of Port Mary Harbour which lies opposite the break in the elevated rim on the west coast. The shore-reefs, which skirt the circumference of Santa Anna, here enclose a remarkable circular lagoon 700 to 800 yards in width, which, entered by a narrow passage, affords a snug anchorage for ships during the S.E. trade. Its depth is about 100 feet (16 to 17 fathoms), thus corresponding with the depth of the basin in the interior of the island, from which it is separated by a barrier of coral detritus, calcareous sand, and shells, that a depression of about 25 feet would, as above observed, completely submerge.

It was only by a detailed examination of this island that I was enabled to learn its true structure. Contrary to my expectations I found that, instead of being composed in mass of coral rock, this upraised atoll had been formed around a submerged volcanic peak which had been first invested, in great part, by a deposit of calcareous mud on which the reef-corals had commenced to grow.

The most interesting locality for the examination of the structure of the island is situated on the north coast. A mass of crystalline granular volcanic rock, an altered dolerite, here protrudes *in situ* 6 to 8 feet above the level of the reef-flat, forming a conspicuous object on the shore, and covering a space of 10 yards in horizontal extent. This ancient peak, if I may so term it, has evidently been denuded by the waves at the present sea-level; and in places most exposed to the action of the sea its surface is formed of water-worn frag-

ments of its own substance joined together in a calcareous cement.* My interest was engaged in a further degree in this locality, on observing that in the vicinity of the protruding mass of volcanic rock the flat was composed in places, not of the ordinary reef-rock, but of a soft argillaceous light-coloured rock that effervesced with an acid. Walking in a few yards from the beach I clambered up a slippery slope† between huge masses of coral limestone that had been detached from a line of cliffs above; and in a few minutes I became aware that I had made a discovery of some importance. A vertical precipice of coral limestone, about 80 feet in height, here rested on a friable argillaceous rock, light brown in colour and sparingly Foraminiferous (*vide* diagram of this locality, Pl. CXLIV. fig. 7). Appended is the description of this rock which Mr MURRAY has given to me :—

A friable earthy rock of a yellowish-brown colour, which, from the small size of the minerals, the absence of Foraminifera that inhabit the bottom, and the scarcity of pelagic forms, resembles somewhat a deep-sea clay; and displays a thin coating of manganese peroxide between the small layers or folds of the rock. A detached concretionary block of manganese peroxide, one or two cubic feet in size, was observed by Lieut. MALAN on the reef-flat on the north coast of this island, not far from the locality where the clay above described was met with. The typical fragment which was brought home is, Mr MURRAY says, quite similar to smaller masses dredged by the "Challenger" and Blake.

Carbonate of Calcium (20·79 per cent.) consists of Coccoliths, *Globigerina bulloides*, *G.* (*Orbulina*) *universa*, *G. conglobata*, *Pulvinulina menardii*, and a few small fragments of Echinoderms.

Residue (79·21) reddish-brown in colour, consists of—

(*a*) *Minerals* (35·00) m. di. 0·08 mm., felspar, hornblende, one or two fragments of magnetite, with a few glassy fragments.

(*b*) *Siliceous Organisms* (1·00), fragment of a sponge spicule noticed.

(*c*) *Fine Washings* (43·21), argillaceous matter, very fine mineral particles and some glassy fragments.

Such being the characters of the deposit underlying the coral limestone, as exposed in this natural section, I now come to the consideration of the coral limestone itself, which is a hard compact rock resting abruptly on the soft underlying deposit. Imbedded in the base of this cliff of coral limestone were two dome-shaped masses of Astræan corals of different species, one of them

* A small patch of massive coral, which still adheres to its surface, probably found attachment during the most recent upheaval of the island (*vide postea*).

† This slippery slope, which is of the argillaceous rock to be immediately referred to, is in part encrusted by calcareous tufa, containing, at an elevation of 15 feet above the sea, a few small angular fragments of volcanic rocks. These fragments would appear to indicate the vicinity of the parent mass further in from the reef-flat.

being apparently an "Orbicella" (Dana). The larger mass measured 4 feet across; and both were in the position of growth. These imbedded corals were elevated about 40 feet above the sea, and from their position in the base of the cliff they must have been buried beneath not less than 80 feet of coral rock; whilst below them, on which in fact they almost rested, was the friable earthy deposit, or in other words, the partially consolidated ooze on which the reef began to grow, or over which it extended by lateral expansion. A coating of calcareous tufa concealed from view the upper portion of the face of the cliff, and thus prevented my examining its structure. It was evident that the undermining action of water which found its way between the base of the cliff and its soft foundation, assisted by the earthquake-shocks to which this region is liable, had caused large masses of the cliff to become detached, thus exposing the foundation of these upraised coral reefs. Another locality in this island in which I was able to find the rock subjacent to the coral limestone was on the western slope of the summit at an elevation of 200 feet above the sea. Here I found a stream issuing from the line of junction of the coral rock and an underlying earthy friable rock. On the south shore of Port-Mary I found masses of red ochre, protruding above the reef-flat.

Before drawing any inferences as to the thickness of the coral limestone in this island, I will refer briefly to the elevated eastern portion of the rim (*vide* Plan and Section Pl. CXLIV. figs. 5 and 6). Near the summit, and at an elevation of 400 feet above the sea, I found a volcanic rock (a hornblende trachyte) exposed *in situ* in the bed of a rivulet. Small fragments of this and of one or two other volcanic rocks (mostly gabbros) occur mingled with masses of coral rock on the summit, and are frequent in the small basin-shaped hollow there situated. With these exceptions, coral limestone forms the surface of the most elevated portion of the island, sometimes displaying faces 25 feet in thickness even at the lip of the summit. The occurrence, however, of a rubbly conglomerate of various volcanic rocks (for the most part gabbros), cemented together by a calcareous material, at the foot of the eastern slope of the island affords sufficient evidence of the proximity of the parent rocks, some of the blocks being from a quarter to half a ton in weight. In accordance with the greater age of the eastern side of the island as dry land, we should have expected to find it almost stripped of its calcareous coverings.

From the foregoing remarks, the following conclusions may be drawn as to the history of the formation of this island. *A submerged volcanic peak, having been covered by the accumulation of a deposit resembling a deep-sea mud, became the base of a coral-atoll, which has been subsequently upheaved together with its foundations, to a height of nearly* 500 *feet above the sea.* The thickness of the coral crust probably does not exceed 150 feet, thus corresponding with the limit of depth at which reef corals are supposed to thrive.

An inspection of the diagram referring to the north coast of Santa Anna will show that probably the underlying soft deposit is not much over 30 feet in thickness in that locality.

The various stages in the movement of elevation which this island has passed through since it first appeared at the surface of the sea are worthy of notice. There was a time in its history when the present summit alone appeared at the surface of the sea as a tiny atoll encrusting a submerged volcanic peak, the remains of which still exist in the shallow basin on the summit before referred to. Then succeeded a period of upheaval, during which, without any lengthened pause, this tiny atoll was raised to a height of from 250 to 300 feet above the sea. This was followed by a prolonged interval of rest during which the main atoll was formed, differing however from the typical atoll in that a pinnacle-islet rose up abruptly to a height of nearly 300 feet from the middle of the east side of the reef. Then commenced another long period of elevation, prolonged to the present time, during which the rim of the atoll has been raised 200 feet above the sea, the waters of which have been excluded altogether. There were pauses during this stage of elevation, the most marked being midway in the stage when that portion of the rim on the south side, which is only 100 feet above the sea, was formed. But in the lower levels, wherever the land descends by a gentle slope to the coast, the retrocession of the sea may be traced in the successive linear heaps of coral masses, 1 to 2 feet in height, which mark slight pauses in the elevation. The most recent upheaval is shown in an ancient line of erosion removed usually from 5 to 8 feet above the present line of wave-action. Where the coast is cliff-bound, the present and ancient lines of erosion are displayed in the faces of the cliffs; but where the coast is low, the old sea-level is to be found in a line of erosion, often worn back into caves, displayed in the base of a line of inland cliffs which are removed at distances varying from a few paces to a hundred yards from the beach, a low strip of recently elevated land supporting cocoa-nut palms and other vegetation intervening.

In concluding this reference to Santa Anna, I will make a few observations on the small adjacent island of Santa Catalina, which from its profile has evidently experienced the same stages in the upheaving movement, which Santa Anna has undergone during its last elevation of 200 feet. Santa Catalina is a low level-topped island elevated about 180 feet above the sea. Here, we have another ancient and originally submerged volcanic peak, which, having become encrusted by coral reefs, has been upheaved to a height of nearly 200 feet above the sea. Although the coral rock apparently forms the whole island, it is in reality but an outer crust, investing as a nucleus some ancient peak once submerged. In the beds of two small streams on the summit, I found exposed in mass a breccio-conglomerate formed of fragments of various volcanic and

calcareous rocks imbedded in an earthy calcareous matrix, together with another dark coloured rock of doubtful volcanic origin. It is therefore apparent that this small island of Santa Catalina existed as a patch of coral reef contemporary with the existence of Santa Anna as an atoll; and that the breccio-conglomerate was formed when the submerged peak, on which the patch of coral reef had based itself, came within the limit of breaker-action.

The Shortland Islands.

This small group of islands consists of one principal island, named Alu, with a number of smaller off-lying islands and islets. Alu Island, which has a breadth of eleven or twelve miles and an elevation of about 500 feet, is composed in its N.W. portion of old and originally deep-seated volcanic rocks (mostly quartz diorites); while the greater part of it, together with the off-lying lesser islands and islets, may be described as made up of more recent calcareous formations.

The accompanying section of Alu (Pl. CXLIV. fig. 8) will explain the structure of this island and will show the relation to each other of the volcanic rocks, the coral limestones (so called), and the soft Pteropod and Foraminiferous deposit which apparently makes up the mass of the island. The two off-lying islets, shown in this section, are two broken lines of barrier-reefs which skirt the weather or S.E. coast of Alu Island. The innermost (marked B) is an ancient reef which has experienced an elevation of about 200 feet above the sea; while the outer reef (marked C) has been in great part formed at the present sea-level, having in no part been upheaved more than 20 feet above the sea. Both lines of reef have within them a lagoon-channel, which in the case of the inner or ancient line of barrier-reef is shoaling and evidently filling up.

The Shortland Islands have been upheaved along an extensive line of barrier-reef that skirts the eastern extremity of the adjacent large island of Bougainville at a distance of about 15 miles from the coast; and a conception may be obtained of the history of their formation by referring to the section before alluded to. Here we have the original land of volcanic rock in the N.W. portion of the group, from which, as from a nucleus, line after line of barrier-reef has been advanced in a south-easterly direction based on a foundation of Pteropod and Foraminiferous muds, and forming ultimately as the upheaving movement continued the large island of Alu, which yet preserves in the ridges of its interior these ancient barrier-reefs now removed far from the coast and elevated some hundreds of feet above the present sea-level. If we may judge from the existence off the weather coast of the double line of barrier-reef, before referred to, the island of Alu is still extending itself in the same direction.

The Soft Pteropod and Foraminiferous Deposit.—This deposit, which in all

its characters resembles the formation of Choiseul Bay, subsequently to be described, apparently composes the bulk of the island of Alu. It is exposed in the banks of the streams that open on the S.E. coast; and may be followed up in the higher parts of their courses in the interior, being also exposed in the lower slopes of the inland ridges at an elevation of 200 feet above the sea. Bedding is rarely well displayed on account of the limited character of the natural sections, the beds displayed having, however, a gentle inclination. In the mass it has the appearance of an argillaceous, earthy, moist rock, containing the shells of Pteropods in abundance, such as *Hyalæa, Diacria, Cleodora, Creseis,* together with numbers of Gasteropod and Lamellibranchiate shells, such as *Murex, Nassa, Hemicassis, Mitra, Natica, Dentalium.* Foraminiferous tests are present in profusion, the large tests of such as *Cristellaria cultrata* and *C. rotulata* can be picked out by the fingers. The otoliths of fish are also abundant. In addition, I found some simple corals referable to the deep-sea genera, *Odontotrochus, Flabellum, Bathyactis* (*symmetrica*?), portions of the shells of a sessile Cirriped; and occasional leaves with their venation in a condition of fair preservation. The Pteropods, bivalves, otoliths, and Foraminifera, are from their numbers most characteristic of this deposit.

Mr Murray thus describes the characters and composition of specimens of this deposit :—

A very friable rock, chiefly composed of volcanic ashes with great numbers of minute imbedded organisms, and resembling the "volcanic muds" in character.

Carbonate of Calcium (33·67 per cent.), consists of Coccoliths, Otoliths, Gasteropod and Lamellibranchiate shells, Pteropod and Heteropod shells, Polyzoa, Serpulæ tubes, Ostracode shells, Echinoderm fragments, and many pelagic and bottom-living Foraminifera. (See list below.)

Residue (66·33), brown, consists of—

(*a*) *Minerals* (40·00), m. di. 0·5 mm., some particles 1·0 mm.; felspar, magnetite, augite, hornblende, mica, quartz, &c.; and a great many glauconitic-like casts of Foraminifera.

(*b*) *Siliceous Organisms.*—None noticed.

(*c*) *Fine Washings* (26·33), argillaceous matter with fine mineral particles, and black fragments of organic matter.

List of Foraminifera.

Miliolina seminulum (rare).
Biloculina depressa ,,
Reophax pilulifera (very few).
Bulimina marginata (rare).
Pleurostomella alternans (few).
Chilostomella ovoidea (many).
Cristellaria rotulata (few).
Cristellaria cultrata (few).
,, calcar ,,
,, aculeata ,,
,, italica ,,
,, echinata ,,
,, vortex ,,
Uvigerina tenuistriata (common).

Uvigerina pygmæa (rare).
Nodosaria hispida (few).
„ papillosa „
„ raphanus „
„ filiformis (rare).
Sagrina virgula (common).
„ columellaris (very common).
Lagena hispida (few).
„ desmophora (few).
Globigerina bulloides (common).
„ „ *var.* triloba „
„ conglobata „
„ dubia „
„ sacculifera „
„ rubra (many).
Globigerina æquilateralis (many).
„ inflata (few).
„ orbulina (universa) (many).
Sphæroidina dehiscens (many).
Ramulina globulifera (rare).
Truncatulina præcincta (few).
„ lobatula „
„ haidingerii „
Pulvinulina menardii (common).
„ „ *var.* tumida „
„ elegans (few).
„ micheliniana „
„ procera „
Pullenia obliquiloculata (few).
„ sphæroides „

The Coral Limestone.—This rock is found capping the inland ridges (as shown in the section) where it does not attain a greater thickness than 30 to 40 feet, being usually much less. It displays considerable variety in its characters; and had I not satisfied myself of its true relation to the underlying soft deposit previously described, I should hesitate in coming to the conclusion that all the varieties belonged to an ancient barrier-reef. By striking the inland ridge (marked A in the section) where it approaches the coast and following along its crest for some three or four miles, one first finds capping the ridge and overlying the soft deposit a hard compact yellowish-white coral limestone containing many *Amphisteginæ*. Further along, as the ridge gradually rises from 150 to 200 feet above the sea, this coral rock displays itself as a chalky limestone capping the ridge and exposed in huge masses, with vertical faces 30 to 40 feet high, on its slopes. These large masses resembled much in their position and appearance ancient reefs still occupying the sites they originally held beneath the sea. The superficial position of this chalky coral limestone and its relation to the underlying soft Foraminiferous deposit are points of some interest.* Appended is the description given by Mr MURRAY:—

A compact chalk-like coral limestone of a cream colour, showing no definite structure, and resembling in section the Lower Chalk of Kent, if the corals are not taken into consideration.

Carbonate of Calcium (95·76 per cent.) consists of Lamellibranchiate shells, Polyzoa, Echinoderm fragments, corals, calcareous Algæ, and Foraminifera as *Nummulina*.

* I found a similar chalk-like coral rock in the small island of Biu which lies off the north end of Ugi Island. This island is only 1½ miles in length and about a hundred feet in height in its centre where this rock was found. It may be briefly described as a patch of coral reef which has been elevated about a hundred feet. In the southern island of the Three Sisters, which are adjacent to Biu, I obtained from the elevated central portion hand-specimens of coral rock which were in part chalky. This island, like Biu, is simply a patch of coral reef which has been upheaved 60 or 70 feet above the sea. The present reefs which skirt the more elevated portion have a rude atoll form.

Residue (4·24), yellowish-red in colour, consists of—

(*a*) *Minerals* (2·00) m. di. 0·1 mm.; magnetite, felspar, hornblende, augite, a few casts of small Gasteropod and Lamellibranchiate shells, and many little spheres.

(*b*) *Siliceous Organisms*, none noticed.

(*c*) *Fine Washings* (2·24), a reddish argillaceous and flocculent material and fine mineral particles.

Another sample of this chalky coral limestone, which was made up chiefly of decomposed coral and calcareous Algæ and held 99·23 per cent. of carbonate of calcium, approaches to a magnesian limestone, on account of the considerable amount of magnesia which it contains.* In a third sample the only recognisable organisms are calcareous Algæ.

As one proceeds further inland along the crest of the ridge, which pursues a very uniform direction, the chalk-like coral limestone is left behind; and rising gradually with the ridge crest to from 300 to 350 feet above the sea, one finds a yellowish-brown Foraminiferous limestone taking its place, both capping the ridge and overlying the soft deposit. The following are its characters:—

A hard compact Foraminiferal limestone, of a yellowish-brown colour. A few simple corals are imbedded in this rock, but the bulk of it is made up of pelagic and bottom-living Foraminifera.

Carbonate of Calcium (76·69 per cent.) consists of Echinoderm fragments, Pteropod shells, and Foraminifera, as follows:—*Globigerina bulloides*, *G. hirsuta*, *G. Orbulina* (*universa*), *Pulvinulina menardii*, *Carpenteria*, *Nodosaria*, and *Amphistegina*.

Residue (23·31), consists of—

(*a*) *Minerals* (6·00) m. di. 0·4 mm.; mica, a few perfect crystals of quartz, felspar, augite, and glassy fragments.

(*b*) *Siliceous Organisms* (10·00), perfect casts of the Foraminifera of a reddish colour.

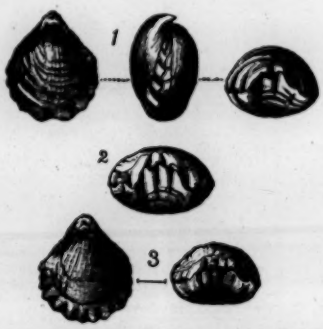
(*c*) *Fine Washings* (7·31), broken down parts of casts of Foraminifera and a few fine mineral particles.

In the elevated barrier-reef through which the section passes, somewhat similar rocks are displayed. In this islet (marked B in the section), which

* Dr Leonard Dobbin, who determined for Mr Murray the carbonate of lime in the rock samples, writes:—"I would draw your attention to the result obtained in the case of the sample 'Shortland Island, No. 587,' where the usual calculation, from the observed weight of carbonic acid, seems to indicate an almost theoretical composition of calcium carbonate. As our method could not give such a result with pure calcium carbonate (the results being in every case at least 2 per cent. too low), I tried to find out the cause of this rather anomalous result. The first and most likely explanation was that the specimen contained considerable quantities of magnesium carbonate, and I find that is the correct explanation, as I found on examining it that a good deal of magnesia is present. I may add that the carbonic acid is not liberated from this specimen with anything like the rapidity with which it is liberated from the other specimens."

is named "Poperang" and has a height of 200 feet, the soft deposit is rarely, if ever, exposed, on account probably of the small erosive power of the streams. Here we find the chalky limestone containing 95 per cent. of calcium carbonate and composed of fragments of Molluscan shells and of Echinoderms, with calcareous Algæ, and the following Foraminifera :—*Globigerina, Polytrema, Carpenteria*, and many *Amphisteginæ*. On the slopes also is exposed a hard Foraminiferal limestone, chiefly made up of the tests of pelagic and bottom-living Foraminifera, and containing 82 per cent. of calcium carbonate. The Foraminifera found in specimens of this rock had crystals of calcspar in their cavities; they include the following :—*Globigerina bulloides* and other species, *G. Orbulina* (*universa*), *Pulvinulina menardii* and *micheliniana, Pullenia obliquiloculata, Planorbulina, Polytrema, Rotalia, Calcarina*, &c.

But the bulk of this islet of "Poperang" is of a unique formation, which may be termed the Rhynconella limestone on account of the number of Brachiopod shells of that genus that are there imbedded. This limestone may be briefly described as a hard grey rock containing numbers of Brachiopod, Gasteropod, and Lamellibranchiate shells, with many simple corals of deep-sea genera, imbedded in a calcareous matrix largely composed of the tests of Foraminifera. I did not observe bedding in this limestone. Further details of the imbedded organic remains and of the composition of the rock are subjoined.



1, 2, *Rh. Grayii*, Solomon Group.
3, *Rh. Grayii*, Fiji Island.

The Brachiopod shells all belong to the same species of Rhynconella. Mr Davidson, to whom they were submitted for examination, is inclined to look upon them as belonging to *Rhynconella Grayii*, a species represented hitherto by a single specimen discovered in the British Museum amongst other natural history objects from the Fiji Islands (?) collected by Mr J. M'Gillivray. This unique specimen was described by Mr S. P. Woodward and figured by Mr Davidson, in the *Annals and Magazine of Natural History* as far back as 1855 (vol. xvi. p. 444, plate 10, fig. 16). Since that time no other recent specimen has been discovered. Hence has arisen the difficulty in pronouncing as to the identity of species since the comparison of a number of fossil specimens with a single recent living one does not afford sufficient material for exact determination.* I am indebted

* The appearance of this solitary specimen of *Rhynconella Grayii*, which is contained in the British Museum collection, might suggest its having been washed out of some recent deposit. I am informed, however, by Mr Davidson that portions of the mantle, peduncle, and some muscular fibres were still attached to the shell.

to Mr DAVIDSON for the accompanying figures of the fossil and living specimens. The Gasteropod and Lamellibranchiate shells are such as live in the shallow waters at the present day. A few *Pteropod* shells occur in the rock belonging to *Hyalæa;* and some *Serpula* tubes are also found. The Simple Corals belong to the deep-sea genera, *Leptocyathus, Stephanophyllia, Odontocyathus, Flabellum,* &c.; but since the shells with which they are associated are of shallow-water habit, as I am informed by Mr E. SMITH, this limestone would appear to be a comparatively shallow-water deposit. The Foraminifera forming largely the matrix of the rock include the following pelagic species :—*Pullenia obliquiloculata, Globigerina hirsuta, G. æquilateralis, G. Orbulina* (*universa*), *Pulvinulina menardii* and *micheliniana,* &c.

The composition of this limestone is as given below :—

Carbonate of Calcium (75·23 per cent.) consists chiefly of Foraminiferous tests of pelagic species with fragments of Echinoderms, Gasteropods, Lamellibranchs, and Brachiopods.

Residue (24·77) consists of—

(*a*) *Minerals* (10·00); felspars, augite, hornblende, and glassy fragments; often surrounded by a red coating, apparently a silicate.

(*b*) *Siliceous Organisms* (11·77), a very large number of casts of the Foraminifera of a red colour.

(*c*) *Fine Washings* (3·00), broken parts of Foraminiferous casts.

Such then are the characters of this limestone rock. The occurrence in it of a species of *Rhynconella* closely allied to, if not identical with, a species that is represented only by a solitary specimen which was described thirty years ago, is one of the more noticeable features in connection with this rock. Another feature is the imbedding of corals belonging to deep-sea genera in a comparatively shallow-water deposit.

Coming now to the outer line of barrier-reef (marked C in the section) it will be sufficient to describe it as formed in great part at the present sea-level. The elevated portion, which has been raised some twenty feet above the sea, is formed in many places of massive reef-corals imbedded in the position of growth.

CHOISEUL BAY.

The large island of Choiseul, as viewed in profile from the islands of Bougainville Straits, has the appearance of a level-topped ridge destitute of peaks, and not elevated more than from 1500 to 2000 feet above the sea. A line of barrier-reef skirts the west end of the island and encloses Choiseul Bay which receives the waters of three large streams that flow through wide belts of mangrove swamps in the lower parts of their courses. About half a mile

from its mouth one of these streams, in cutting across the extremity of an outlying spur of the neighbouring hills, exposed a soft earthy rock bedded with a gentle inclination of 2° to 3°, and abounding with organic remains. This rock resembles the prevailing formation of Alu, the principal island of the adjacent Shortland Islands already described. Further up the stream, the same deposit was exposed in the banks, until I reached a narrow gorge rather over a mile direct from the coast, the sides of which were of a chalky coral limestone. This limestone I traced up the slopes of an adjoining cluster of hills to an elevation of about 120 feet above the sea. A grained limestone* then appeared at the surface, and composed the summit of the hill, which was elevated about 200 feet above the sea.

Subsequently I ascended another stream which opened into the bay. After following its course through the mangrove belt for about two-thirds of a mile, I struck off on foot through the swamp, and came upon a mound about 35 feet high—an outlier of the neighbouring hills—which rose up like an island from the midst of the swamp, and was formed of the same deposit, similarly laden with organic remains, as that which I had observed during my ascent of the neighbouring stream. Ascending one of the outlying hills to a height of about a hundred feet above the sea, I found the same deposit, but not sufficiently exposed, however, to display bedding.

Unfortunately the uncertain reputation of the natives restricted my field of observation. I was, however, able to satisfy myself that the mass of the low-lying land near the coast was of this soft earthy deposit, the characters of which will be now described.

When in the mass, it has the appearance of an argillaceous earthy rock, somewhat moist and effervescing with an acid; and displaying to the eye numerous Pteropod shells of the genera *Hyalæa, Diacria,* &c., Lamellibranchiate and Gasteropod shells, the tubes of *Dentalium* being especially noticeable; otoliths of fish; macroscopic tests of such Foraminifera as *Cristellaria cultrata, Nodosaria soluta,* &c., together with numbers of shells of the more microscopic kinds; and, lastly, often fragments of leaves. Subjoined is the description given by Mr MURRAY of samples of this deposit:—

A very friable rock, of a greenish-grey colour, having the composition of a Foraminiferous ooze mixed with much volcanic débris (it resembles the Shortland deposits in all its characters).

Carbonate of Calcium (33·14 per cent.) consists of otoliths of fish, Pteropod and Heteropod shells, Gasteropod and Lamellibranchiate shells; Serpula tubes, Ostracode valves, Echinoderm fragments, with many pelagic and bottom-living Foraminifera (*vide* List).

* This grained limestone has not been examined by Mr MURRAY. It, however, closely resembles in appearance the Foraminiferal limestones of Alu, and is probably of the same character.

Residue (66·86), of a dark green colour, consists of :—

(*a*) *Minerals* (40·00) m. di. 0·3, some fragments 1·0 to 2·0 mm.; mica, quartz, felspar, hornblende, magnetite, augite; many glassy fragments. A few beautifully formed quartz crystals were found in this rock.

(*b*) *Siliceous Organisms.*—None noticed.

(*c*) *Fine Washings* (26·86).—Green organic-like substance with argillaceous matter and fine mineral and glassy fragments.

Many glauconitic-like casts of most of the organisms mentioned above were also obtained in this rock.

List of Foraminifera.

Biloculina ringens (rare).
Miliolina seminulum (several).
Reophax pilulifera (few).
Textularia sagittula (rare).
Bulimina marginata (rare).
Nodosaria soluta (several).
„ raphanus (rare).
Rhabdogonium tricarinatum (rare).
Virgulina subsquamosa (few).
Uvigerina tenuistriata (many).
Sagrina virgula (common).
„ columellaris (common).
„ striata (few).
Frondicularia alata (rare).
Cristellaria cultrata (few).
„ papillosa (few).
„ calcar (few).
„ aculeata (few).
„ articulata (few).
Cristellaria compressa (rare).
„ dentata (rare).
„ italica (few).
Globigerina bulloides (common).
„ „ *var.* triloba (common).
„ sacculifera (common).
„ dubia (many).
„ æquilateralis (few).
„ Orbulina (universa) (many).
Sphæroidina dehiscens (many).
Pullenia obliquiloculata (rare).
Cymbalopora poeyi? (few).
Truncatulina lobatula (rare).
„ rostrata (many).
„ præcincta (many).
Ramulina globulifera (rare).
Pulvinulina menardii (common).
„ „ *var.* tumida (common).
„ elegans (few).

The chalky coral limestone, before referred to as forming the sides of a gorge in the higher part of one of the streams, presents most of the characters of true chalk. It was exposed in faces 20 feet in thickness; but I was unable to ascertain its position relative to the soft Foraminiferous deposit exposed in the sides of the stream lower down. However, a similar chalk-like limestone in the Shortland Islands overlies the softer deposit, as noticed in the description of those islands.

Mr Murray describes the characters of specimens of this interesting rock which I sent to him, as follows :—

A friable chalky coral limestone rock, of a light creamy colour, showing no definite structure.

Carbonate of Calcium (94·19 per cent.) consists of Lamellibranchiate shells,

coral, Serpula tubes, Echinoderm fragments, Alcyonium spicules, and Foraminifera, as *Globigerina*, *Polytrema*, *Rotalia*, and *Nummulina*.

Residue (5·81) of a light brown colour, consists of—

(*a*) *Minerals* (2·00), m. di. 0·1 mm.; felspar, augite, hornblende, magnetite, and a few glassy fragments.

(*b*) *Siliceous Organisms* (1·00); a few fragmentary sponge spicules.

(*c*) *Fine Washings* (2·81), consisting of a flocculent substance.

Sections of this rock show specimens of all the organisms mentioned above, together with calcareous Algæ and *Carpenteria*.

In concluding these observations on this locality, I may remark on the probable geological character of the elevated interior of this portion of Choiseul Island. Judging from my partial examination of the lower slopes, and from the significant profile of the high land behind, I think it probable that the western portion of this large island will be found, on examination, to exhibit the same geological structure as that which characterises the islands of Treasury, Ugi, and other islands in the Solomon group.

St Christoval.

The large island of St Christoval, which is rather over 70 miles in length and about 4100 feet in elevation, may be taken as probably representative, respecting its raised calcareous formations, of the larger islands of the Solomon group. My examination of the island was considerably curtailed on account of the uncertain disposition of the natives. I was able, however, to obtain a general acquaintance with the north coast and its vicinity, together with such knowledge of the interior of the island as a traverse across its breadth from Wano to Makira and various ascents, never exceeding 1400 feet, could afford me.

The north coast is skirted by a margin of low-lying land of varying breadth, which in its turn is fringed by shore-reefs along a large portion of its extent. This low-lying margin is either of calcareous sand, shells, and coral detritus, imperfectly mixed with humus, when it is raised from 2 to 4 feet above the sea; or it is of coral rock elevated 5 or 6 feet at the sea-coast, and rising to some 15 or 20 feet as one proceeds inland.

The general character of the mountainous interior is that of a parallel series of long level-topped and gently rounded ridges, separated by deep valleys from each other, and composed, as far as my limited field of observation enables me to judge, of ancient volcanic rocks. From the elevated interior several lofty spurs descend with a gentle slope and even profile to the north coast, where they protrude as bold headlands that often retain an elevation of 800 or 1000 feet. My observations have shown that the masses of these headlands are of old basic rocks; whilst more recent calcareous formations encrust their

lower slopes. Such is without doubt the geological structure of Cape Keibeck, which has an elevation of over 1100 feet at the coast. I traced the coral limestone as high as 500 feet above the sea when examining this cape, this being the greatest elevation at which the coral rock came under my observation in St Christoval. In many parts of the coast a fawn-coloured crystalline limestone, with homogeneous texture, in which sometimes reef débris can be observed, in fact just such a rock as might arise from the consolidation of the white ooze of coral reefs, takes the place of the coral rock. I followed it up to about 500 feet above the sea. It is probably of no great thickness, its relation to the underlying volcanic rocks being often displayed in the courses of the smaller streams.

I will here relate my experience in the case of a hill that lies on the east side of Wano Bay, since it is very typical of my experiences in other parts of this coast. During two different ascents, in which I purposely avoided the courses of the streams, I traced the coral rock on the surface to a height of 150 feet above the sea, and at the summit, 400 feet up, I found the fawn-coloured limestone before alluded to. In no place during these ascents did I find a fragment of volcanic rock at the surface; but when, taking advantage of the deep gulleys that had been worn by the streams into the mass of the hill, I availed myself of the rude sections of the hill's substance there displayed, I found in position the old volcanic rocks (altered dolerites).

These volcanic rocks are not uncommonly exposed protruding in mass above the flats of coral formation which skirt the coast. Doleritic rocks project through the coral rock on the point east of Wano Bay; whilst in the vicinity of Cape Keibeck, a dolerite, from which the coral rock that originally invested it has been but partially removed, protrudes in mass to a height of 10 or 12 feet above the reef-flat. Pebbles and small blocks of volcanic rocks are frequently to be observed in the reef-rock all along this north coast of St Christoval.

With reference to the estimation of the thickness of these encrusting calcareous deposits, I have no certain data. The fawn-coloured limestone, as has been remarked above, can be of no great thickness; whilst the coral limestone, which I rarely saw exposed in faces exceeding 20 feet in height, probably constitutes a thinner crust than I have found in other parts of the group. Without doubt these calcareous envelopes originally extended to far higher levels, from which they have been stripped by the agency of subaerial denudation, which in these regions of great rainfall must be very rapid. From my observations of the rainfall in this archipelago, I am inclined to estimate the annual amount at usually not much under 150 inches.* Of the rapid

* This estimate refers only to the coast. In the elevated interiors of the larger islands the annual fall is probably twice as much; whilst on the lofty summits of Bongainville and Guadalcanar the rainfall is still greater.

degradation of the surface which these calcareous districts undergo during a heavy fall of rain, of as much as 2 to 3 inches in the same number of hours, I have been a frequent witness. In a few minutes the whole hill-slope discharges a continuous sheet of muddy water, the rivulets swell to turbid streams, and the water rushes down the permanent courses with the roar of a mountain torrent. After the rain-storm has passed away, the band of muddy water that fringes the whole length of coast, to a distance of one-quarter or one-third of a mile from the shore, indicates the loss of material which the land surface has sustained.

The bedded Foraminiferous deposit that forms the mass of the neighbouring island of Ugi is rarely represented among the coast formations of St Christoval. I came upon it only once in position exposed in the banks of a stream near the coast.* The coral rock and the fawn-coloured limestone here appear as a rule to rest directly on the volcanic rock. Occasionally in different parts of the coast I found a coarsely grained deposit composed of the water-worn débris of volcanic and coral rocks with a few shells imbedded.

The Florida Sub-Group.

From the few traverses which I made in this sub-group I learned that the western islands are more of volcanic formation, whilst the large island on the east side of the narrow passage which bisects the main mass of land is composed on the surface largely of recent calcareous formations. It is to this eastern island that I will restrict my remarks. Traversing it in a S.W. direction from the vicinity of Mboli Harbour to the village of Gaeta, I found an argillite and a dark trap-rock scantily exposed in the lower hill-slopes. At a height of 500 feet a grained limestone associated with a limestone conglomerate appeared at the surface. The coral limestone occurred at an elevation of 600 feet above the sea, and formed the surface up to rather over 900 feet—the greatest elevation I attained. In one locality it displayed a joint-structure. Descending on the other side of the range, the grained limestone occurred at the same height, and I traced these calcareous formations down to about 200 feet above the sea. In the vicinity of the village of Gaeta, which is elevated rather over 100 feet, a volcanic rock appeared at the surface and was exposed in the bed of a neighbouring stream.

I subsequently made an excursion into the interior of the island for a distance of between two and three miles N.N.E. from Gaeta. I traversed a region of coral limestone gradually rising until an elevation of about 350 feet

* A similar rock, but sparingly Foraminiferous, occurs on the slopes of Cape Keibeck at an elevation of 500 feet above the sea.

was attained, when I descended into a deep valley and followed up the bed of a large stream, which finally emerged from a cavern of considerable dimensions in the face of a hill of coral limestone. This cavern was first visited by the Rev. Mr PENNY of the Melanesian Mission, and was subsequently explored by Bishop SELWYN, to whom I was indebted for the opportunity of examining it. The interior, the entrance to which is between 60 and 70 feet in height, presents the usual features of these subterranean cavities. A series of lofty chambers, connected by narrow passages and containing numerous stalactitic and stalagmitic columns in all stages of formation, some of them between 1 and 2 feet in diameter—such is the character of this cavern which Bishop SELWYN found to be about 750 yards in length. I emerged from the farthest mouth into the bottom of a deep valley, across which the coral limestone hill lies as a dam through which the stream has found its way. In the bed of the stream, as it follows its subterranean course, there are numerous blocks and pebbles of a dark crystalline volcanic rock and of a marley rock, of which I was unable to find the parent rocks in the valley above. They are probably traversed by the stream in its passage through the hill, where they would be concealed from view by the stalagmitic and stalactitic deposits. The marl presumably represents the immediate foundation of the limestone, and will be found to cover the crystalline volcanic rock. From the presence of these rocks in the bed of the stream as it flows through the caverns, I suspect that these subterranean passages traverse the base of the limestone ; and on this supposition the thickness of this coral limestone would be not greater than the height of the hill which is pierced by the stream, *i.e.*, about 150 feet.

The general conclusion that I formed of the structure of this eastern island of the Florida Sub-group was, that the calcareous rocks were merely superficial formations encrusting a nucleus of volcanic rocks which has been occasionally exposed to view by the denuding forces.

THE CLASSIFICATION OF THE SOLOMON ISLAND RECENT FORMATIONS.

These rocks may be grouped into two chief classes, according to the proportion of volcanic débris they contain.

The First Class comprises those rocks which, being largely composed of such volcanic débris mixed with the tests of Foraminifera, Pteropods, and other Molluscs, have a composition very similar to that of the volcanic muds at present forming around oceanic volcanic islands in the Pacific. These rocks contain both pelagic and bottom forms of Foraminifera, lists of which have been given in the previous pages. The soft rock, resembling a deep-sea clay, which underlies the elevated reef-mass at Santa Anna, may be referred to this principal division of the rocks ; but, as shown in the description on page 558,

it differs essentially from all the other deposits of the class. Four prevailing kinds of these rocks may be distinguished.

(1) A friable rock, containing from 5 to 20 per cent. of carbonate of lime, and displaying to the eye only the white specks of minute Foraminiferous tests with a few of macroscopic size, such as *Cristellaria cultrata* and *Nodosaria soluta*, Molluscan shells being rarely observed. Rocks of this character form the masses of Treasury and Ugi Islands; and their composition is described in detail in the sections treating of those islands (*vide* pages 547, 551, 552).

(2) A very friable rock, containing from 30 to 35 per cent. of carbonate of lime, and inclosing in great numbers the shells of Pteropods, Gasteropods, Lamellibranchs, together with otoliths of fish, simple corals, and numbers of Foraminiferous tests, many of them macroscopic. Rocks of this character largely compose Alu, the principal island of the Shortlands, and are exposed in the low hills in the rear of Choiseul Bay (for the detailed descriptions, see pages 562, 567).

(3) A hard grey fossiliferous limestone, containing usually about 60 per cent. of carbonate of lime, and much volcanic débris. It is chiefly composed of the broken down fragments of corals and Lamellibranchiate shells, with calcareous Algæ, and a few Foraminifera. This rock is exposed in the lower courses of the Treasury Island streams, where it gives rise to water-falls on account of its greater hardness. Its further description is given on page 552.

(4) Coarse rocks, composed of the fragments of volcanic and coral rocks in rounded grains. Occasionally larger fragments, together with shells, are imbedded. These rocks occur on the northern slopes of St Christoval, near the coast.

The Second Class includes those rocks which are largely composed of coral, Molluscan shells, Foraminiferous tests, and calcareous Algæ, with but a small proportion of volcanic débris. The share that each of these four principal constituents takes in the building up of the rock differs widely; and on this basis the following groups have been made. Yet to the great majority of these rocks, if not to all, the term of coral limestone is quite applicable in its widest sense. Probably, however, the term "coral-reef formation" would be preferable, as including the variously composed rocks that are being formed in connection with coral-reefs. Whether the rock is formed by the upward growth of successive tiers of large masses of reef-corals, or whether it is formed from the fragments of such corals broken off by the waves and mixed with shells and other organisms in varying proportions, such as must be forming on the outer slopes of reefs, it has the same coral origin. For the same

reason, the calcareous muds and sands found at the bottom of the lagoons are of coral origin, representing as they do the final stages of the process of degradation. The variety in character exhibited in the following groups of coral limestones may be thus in a great measure explained :—

(1) Coral rocks, properly so called, which are merely the massive reef-corals in different stages of fossilisation. The porous and small-celled corals, as the *Poritidæ*, are the first to lose their characteristic structure, usually passing through a drusy stage, when they present a saccharine appearance, and finally, by the continued percolation of water charged with *calcium carbonate*, assuming a compact texture exhibiting no coral structure to the eye. Such coral rocks are best observed at the coast.

Here I may refer to a peculiar variety of coral rock which is not uncommon on the south side of Treasury Island on the higher slopes of the hills, as high as 750 feet above the sea. It is a hard, compact, partly crystalline greyish rock, chiefly made up of a coral belonging to the Fungidæ, which Mr J. J. QUELCH, to whom fragmentary specimens were submitted for examination, has identified as being with very little doubt *Leptoseris striatus* (Kent), a species founded for the reception of a rare coral collected by Capt. Sir E. BELCHER at Borneo, (the only other recorded specimen being from Madagascar (?). This coral is not included amongst my collection of reef-corals in the Solomon Islands. It may probably, however, occur in the deeper water.*

(2) Coral rocks, which are chiefly made up of calcareous Algæ,† fragments of Molluscan shells, corals, and Echinoderms, the interstices being filled up by the tests of Foraminifera and other small calcareous organisms. In the composition of such rocks, coral fragments take only a secondary part. The majority of coral limestones that I found in the Solomon Islands may be referred to this division. They are usually white in colour, but often reddish or yellowish brown, being hard, compact, and sometimes partly crystalline in texture, and often displaying a fragmental structure. The percentage of calcium

* In one of the islands of the Pelew Group, Professor SEMPER observed that the base of the coral cliffs was formed entirely of species of *Lophoseris* mixed with other deep-sea forms, the higher portion of the cliffs containing *Astræidæ*, *Poritidæ*, *Madreporidæ*, &c. *Lophoseris* and *Leptoseris* belong to the same sub-family of the *Fungidæ*. See *The Natural Conditions of Existence*, &c., p. 275, London, 1881. I am inclined to consider this variety of rock in Treasury Island as representing the base of the elevated reef-masses, since it only occurs on the higher and more denuded slopes.

† Some specimens of coral rock which I obtained at Santa Anna were entirely formed of the joints of a calcareous Alga, resembling apparently the genus *Halimeda*, which are found commonly in the soundings off the outer edge of the present coral reefs.

carbonate in this group varies between 90 and 95, the *residue* consisting of the minerals named in the subjoined analysis, of Foraminiferous casts, and argillaceous matter.

The Composition of a Typical Sample.

Carbonate of Calcium (94·47 per cent.), consisting of the various materials mentioned above.

Residue (5·53), consisting of—

(*a*) *Minerals* (1·00) m. di. 0·2 mm.; augite, hornblende, felspar, magnetite, and a few glassy fragments.

(*b*) *Siliceous Organisms* (2·00), casts of Foraminifera, &c., of a red colour.

(*c*) *Fine Washings* (2·53), broken down parts of casts of Foraminifera, fine mineral particles, argillaceous matter, and a red material—probably oxide of iron.

(3) Compact fawn-coloured crystalline limestones of a homogeneous texture, apparently formed by the consolidation of the ooze found at the bottom of the lagoons inside coral-reefs. These rocks are of common occurrence on the lower slopes of the large island of St Christoval, where they overlie the volcanic rocks of the district. They are sometimes coarse-grained.

(4) Chalk-like coral limestones, which contain about 95 per cent. of calcium carbonate, and are chiefly composed of the fragments of Molluscan shells, Echinoderms, corals, calcareous Algæ, and Foraminifera. These rocks, therefore, in their general composition resemble the rocks of the second group of coral limestone differ conspicuously in their chalk-like appearance and in being more friable. They occupy, however, the usual surface position of other coral rocks (as shown in the description of the Shortland Islands, page 563), although being by no means of common occurrence. They may sometimes be found in the central elevated portions of islands like Biu, which have been formed by the partial upheaval of coral reefs. I found them only on four occasions in the Solomon group, viz., at Alu, Choiseul Bay, the Three Sisters, and Biu Island Their composition is described at length in pages 563, 568.

(5) The Foraminiferal limestones, which are grey or yellowish-brown in colour, hard and compact in texture, and are chiefly made up of the tests of pelagic and bottom-living Foraminifera. They contain generally from 75 to 85 per cent. of calcium carbonate, their typical

* White men resident in the group tell me that chalk-like rocks are found in the island of Ulaua, which lies near the Three Sisters.

composition being described on page 564. They usually, like the coral limestones, are found at the surface; and in the island of Alu they overlie the soft Pteropod deposits, as described on page 564. In Treasury Island they occur on the tops of the lower hills.

In the island of Treasury, however, I found exposed in a stream-course a Foraminiferal limestone of somewhat different character, and occupying the usual surface position of the coral limestones. Appended is the description of this rock.

A hard, compact, grey, Foraminiferal limestone, showing a simple coral imbedded, the whole rock chiefly composed of pelagic Foraminifera.

Carbonate of Calcium (66·26 per cent.) consists of the following Foraminifera—*Globigerina bulloides hirsuta, G.* (*Orbulina*) *universa, Pullenia obliquiloculata, Pulvinulina menardii, Amphistegina.*

Residue (33·74), brown colour, consists of—

(*a*) *Minerals* (20·00) m. di. 0·5 mm.; felspar, hornblende, augite, magnetite, mica, and many glassy fragments.

(*b*) *Siliceous Organisms* (3·00), casts of Foraminifera.

(*c*) *Fine Washings* (10·74), argillaceous matter and fine mineral particles.

The organisms in this rock, together with the minerals, are similar to those found in deposits of modern seas near volcanic islands at depths of from 500 to 800 fathoms. The Foraminifera are identical with those found in the surface waters of the tropics at the present day.

(6) The Rhynconella limestone, which was only found in one locality, viz., in the islet of Poperang in the Shortland Islands, may be briefly described as composed of a large number of Brachiopod, Lamelli-branchiate, and Gasteropod shells, together with many simple corals of deep-sea genera imbedded in a matrix largely formed of pelagic Foraminiferous tests. A detailed description of this limestone is given on pages 565 and 566.

The Occurrence of Flints.

This paper would be incomplete without a reference to the occurrence of flints in these islands. They are usually found where the soil has been disturbed for purposes of cultivation; and I was *never successful in finding their source.* They occur, however, together with a chalky rock, on the beaches of the island of Ulaua. Having been unable to visit this island, I would recommend future visitors who may land there to pay attention to this

point, which was one constantly before my mind during my examination of the calcareous formations of these islands. The explanation of their origin held by many natives is that they have fallen from the sky; and since many of these flints have all the characters of flint implements of the palæolithic type, we are thus reminded of a similar superstition prevalent amongst the agricultural classes of some of the English counties as to the source of the polished stone implements named "celts." (For further information on this subject *vide* some notes of my own read by Professor LIVERSIDGE before the Royal Society of New South Wales [*Journal* for 1883, vol. xvii. p. 223.])

CONCLUSION.

[*Added December* 16, 1885.]

From the general character of these calcareous formations it may be safely inferred that they will be found wherever there has been elevation during the recent period in regions where coral reefs are flourishing. Amongst other localities we may look to the West Indies, the Indian Archipelago, New Guinea (more particularly the south coast), New Britain, New Ireland, the Santa Cruz Group, the New Hebrides, the Loyalty Islands, New Caledonia, and the Fiji and Tonga Groups, as likely to possess at the sea-border formations of a similar character.

I have thought it best to add to the completeness of this paper by making a few general remarks on the general bearing of these observations.

In this, the largest of the Pacific groups, I not only found existing fringing-reefs, barrier-reefs, and atolls, but I discovered pre-existing reefs of these three chief classes, which have been recently elevated to a height sometimes of several hundred feet above the sea. My observations on these recently elevated reefs and their foundations have enabled me to approach the problem of the formation of coral reefs by the inductive rather than by the *a priori* method, for it is evident that in passing from the consideration of a probable cause of the formation of existing reefs to the examination of ancient reefs that have been raised with their foundations above the sea, we enter a domain of greater certainty. I will begin by briefly restating the principal points of this paper.

In the first place, there are numerous small islands and islets less than a hundred feet in height, which are composed entirely of coral limestone. Then there are islands of larger size, which are composed in bulk of partially consolidated volcanic muds, such as are at present forming around oceanic volcanic islands. Coral limestones encrust the lower slopes of these islands, and do not attain a greater thickness than 150 feet. In the next place, we have islands of similar structure, but possessing in their centre some ancient volcanic peak

that was once submerged. Then there are islands in which the volcanic peak has become an eccentric nucleus, from which line after line of barrier-reef has been [advanced overlying the volcanic muds, islands in which I did not find the coral limestone of a thickness of 100 feet. Then we have the upraised atoll, such as Santa Anna, which, within the small compass of a height of 470 feet, displays the several stages of its growth,—first, the originally submerged volcanic peak, then the investing soft deposit, and over all the ring of coral limestone that cannot far exceed 150 feet in thickness; lastly, we come to the mountainous islands formed of old volcanic rocks, such as St Christoval, which, although over 4000 feet in height, showed to me no calcareous envelopes at a greater height than 500 feet above the sea, the coral limestone crust being even thinner than in the smaller and more recent islands.

I purpose now to draw four limited inferences from these facts of observation, without reference to any particular view that may be held on the subject of the formation of coral reefs, and to compare such inferences with the prevailing views on that subject.

(1) *That these upraised reef-masses, whether atoll, barrier-reef, or fringing-reef, were formed in a region of elevation.*—This is self-evident. The last upheaval that occurred, of which I found proofs in different parts of the group, was to the extent of about 5 feet, but at the present day there are signs of this movement being still in operation; and for the purposes of future observation I have established datum-marks in different islands. This, therefore, being a reign of elevation, it is apparent that that portion of Mr DARWIN's theory of coral reefs, which ascribes the formation of atolls and barrier-reefs to a movement of subsidence, cannot be applied to the islands of the Solomon Group, since we here find upraised atolls and barrier-reefs associated with existing reefs of the same description. This conclusion accords with the results obtained by Professor SEMPER in the case of the Pelew Islands, and by Professor A. AGASSIZ in the case of the Florida reefs.

(2) *That such upraised reefs are of moderate thickness, their virtual measurement not exceeding the limit of the depth of the reef-coral zone.*—Amongst the numerous islands which I examined I never found one that exhibited a greater thickness of coral limestone than 150 feet, or at the very outside 200 feet. One of the corollaries of the theory of subsidence is concerned with the great thickness of atolls and barrier-reefs. My observations in this region, and it is such regions that can alone afford such evidence, show that atolls and barrier-reefs can be formed with no greater thickness than they would possess in accordance with the depths in which reef-corals thrive, the vertical thickness of the reef not exceeding the depth of the reef-coral zone. . . . . The only objection worthy of attention that has been advanced against the atoll-theory

of Mr DARWIN was, in the opinion of Sir CHARLES LYELL,* the circumstance that, as far as was known, no bed or formation of coral of any thickness had been discovered. This objection, which was proposed by Mr MACLAREN in 1842, derives additional force at the present day in the light of my observations in the Solomon Islands.

(3) *That these upraised reef-masses in the majority of islands rest on a partially consolidated deposit which possesses characters of the "volcanic muds," which were found during the "Challenger" Expedition to be at present forming around volcanic islands.*

(4) *That this deposit envelops anciently submerged volcanic peaks.*

These two latter conclusions corroborate in a remarkable manner the views, based on the observations of the "Challenger" Expedition, which Mr MURRAY has advanced. I will cite the structures of two islands to illustrate these views. In the small island of Santa Catalina I found that the elevated reef was based on volcanic rock with the intervention of a thin brecciated conglomerate. In the island of Treasury I found the volcanic rock covered by a soft partially consolidated volcanic mud, which attained the thickness of some 300 or 400 feet, and was itself encrusted on the lower slopes of the island by the elevated reef-mass. In the one island the volcanic peak had been first exposed to breaker-action before the reef-corals established themselves. In the other island the submerged volcanic peak was first brought within the reef-coral zone by the deposition of layers of volcanic mud, assisted by the movement of elevation.

With reference to my own bias on this subject, I may here add that during the first eighteen months I passed in the Solomon Islands I was only acquainted with the theory of subsidence; and that after having failed to make my observations harmonise with the theory of Mr DARWIN, I collected my facts with a very confused idea of the direction towards which they were tending. It was therefore a cause of great satisfaction to myself when I first became acquainted with the views of Mr MURRAY.

I will close this paper with a few remarks on the amount of elevation that has occurred in this region in recent times. It is, however, difficult to gauge it. So great has been the subærial denudation in these islands, that although the elevatory movements have brought up to our view a deep-sea clay with its concretions of manganese and a Foraminiferal limestone that was probably formed in a depth of from 500 to 800 fathoms, two rocks which occur in islands at opposite ends of the group, yet, notwithstanding this great upheaval, the calcareous envelopes usually disappear from the slopes of the large volcanic islands at heights of 500 or 600 feet above the sea, and never came under my observation in such islands at greater elevations than 900 feet. In the

* *Principles of Geology*, 12th edit., vol. ii. p. 612.

calcareous islands the greatest height at which the soft deposits occurred was 1150 feet, which was the greatest elevation at which I found any of the recent calcareous formations in this group. They probably occur in the western end of Choiseul at an elevation of 1500 feet and over.

EXPLANATION OF PLATES CXLIV., CXLV.

Heights in feet; depths in fathoms. Arrows indicate the dip; horizontal beds shown by a cross, thus +.

Plate CXLIV.

Fig. 1. Plan of Ugi Island, $\frac{1}{2}$ inch to a mile.

Fig. 2. Ideal section of Ugi Island, intended to illustrate the relative thinness of the coral limestone.

Fig. 3. Plan of Treasury Island, $\frac{1}{2}$ inch to a mile.

Fig. 4. Ideal section of Treasury Island, adapted to show its principal structural features.

Fig. 5. Plan of Santa Anna Island, $\frac{1}{2}$ inch to a mile.

Fig. 6. Section of Santa Anna Island, drawn on a true scale of 2 inches to a mile.

Fig. 7. Diagram showing the relative position of the raised coral rock and its foundation to the mass of volcanic rock *in situ* on the reef flat; north coast of Santa Anna Island.

Fig. 8. Ideal section of Alu Island, showing the relation to each other of the coral limestone, the soft Pteropod and Foraminiferous deposit, and the volcanic rock.

Plate CXLV.

Fig. 1. Section of a compact grey Globigerina limestone from Treasury Island (see page 576). The rock contains 66·26 per cent. of carbonate of lime, consisting chiefly of species of pelagic Foraminifera, such as *Globigerina bulloides*, *G. hirsuta*, *G.* (*Orbulina*) *universa*, *Pullenia obliquiloculata*, and *Pulvinulina menardii*; *Amphistegina*, and one or two other bottom living Foraminifera. The organisms are cemented by carbonate of lime, sometimes crystallised in rather large grains (*d*). The mineral particles consist of (1) plagioclase-felspar, presenting the extinctions of labradorite; sometimes these crystals are twinned following the albitic law (*c*); sometimes they are twinned following the law of pericline. The crystal (*e*) shows a plagioclastic section, exhibiting at the same time the twinning, following the law of albite and pericline; (2) fragments of hornblende; one of these (*a*) is cut perpendicular to the crystallographic axis, and presents the hexagonal contours, and the cleavage lines crossing at an angle of 124°; (3) fragments of augite; the section (*b*) of this mineral presents two individuals grouped with their axes parallel; the section is octagonal, and crossed by the cleavages at right angles; (4) fragments of magnetite and biotite.

Fig. 2. Section of a tufa of an augite-andesite, from the central region of Treasury Island (see page 551). The rock contains 7·74 per cent. of carbonate of lime, which consists of a few coccoliths, several species of *Globigerina*, and fragments of Echinoderms. The ground-mass is composed of particles of volcanic glass, magnetic particles, and small decomposed mineral fragments. The larger minerals are lamellæ of plagioclase (*d*), twinned following the albite law, with the extinction of labradorite; also twinned, following the law of Baveno (*a*); sections of augite (*b*) more or less parallel to the axis, with a twinning following the orthopinakoid; and crystals of augite (*c*) with a black glass particle attached, proving that the crystal was not formed *in situ*; also some hornblende. The presence of the *Globigerinæ* and Echinoderm particles show that the tufa was formed under water in which the surface organisms lived.

Fig. 3. Section of a compact coral limestone from N.E. side of Treasury Island, consisting almost entirely of crystallised carbonate of lime, and fragments of the following organisms:—Gasteropod and Lamellibranch shells, Echinoderms, corals, calcareous Algæ, *Serpula* tubes, and Foraminifera of the genera *Carpenteria*, *Polytrema*, *Tinoporus*, *Gypsina*, *Calcarina*, *Amphistegina*, *Cycloclypeus*, *Nummulites*, *Globigerina*, and *Pulvinulina*.

Fig. 4. Section of a compact Rhynconella or Foraminiferal limestone, from Poperang Island (see pages 565 and 566), containing 75·23 per cent. of carbonate of lime, which consists chiefly of pelagic and other Foraminifera, shells of Rhynconella, and fragments of Gasteropods, Lamellibranchs, and Echinoderms. A considerable quantity of the carbonate of lime is crystallised with a rhombohedral cleavage (*c*). The interior of the Foraminifera shells is frequently filled with a reddish substance. The mineral particles are—(1) fragments of plagioclase very much altered, with the twinning of albite and pericline (*d*); (2) hornblende, often zonary (*a*), with inclusions of apatite (the little white spot in the section) or twinned (*b*); and (3) black mica (*e*).

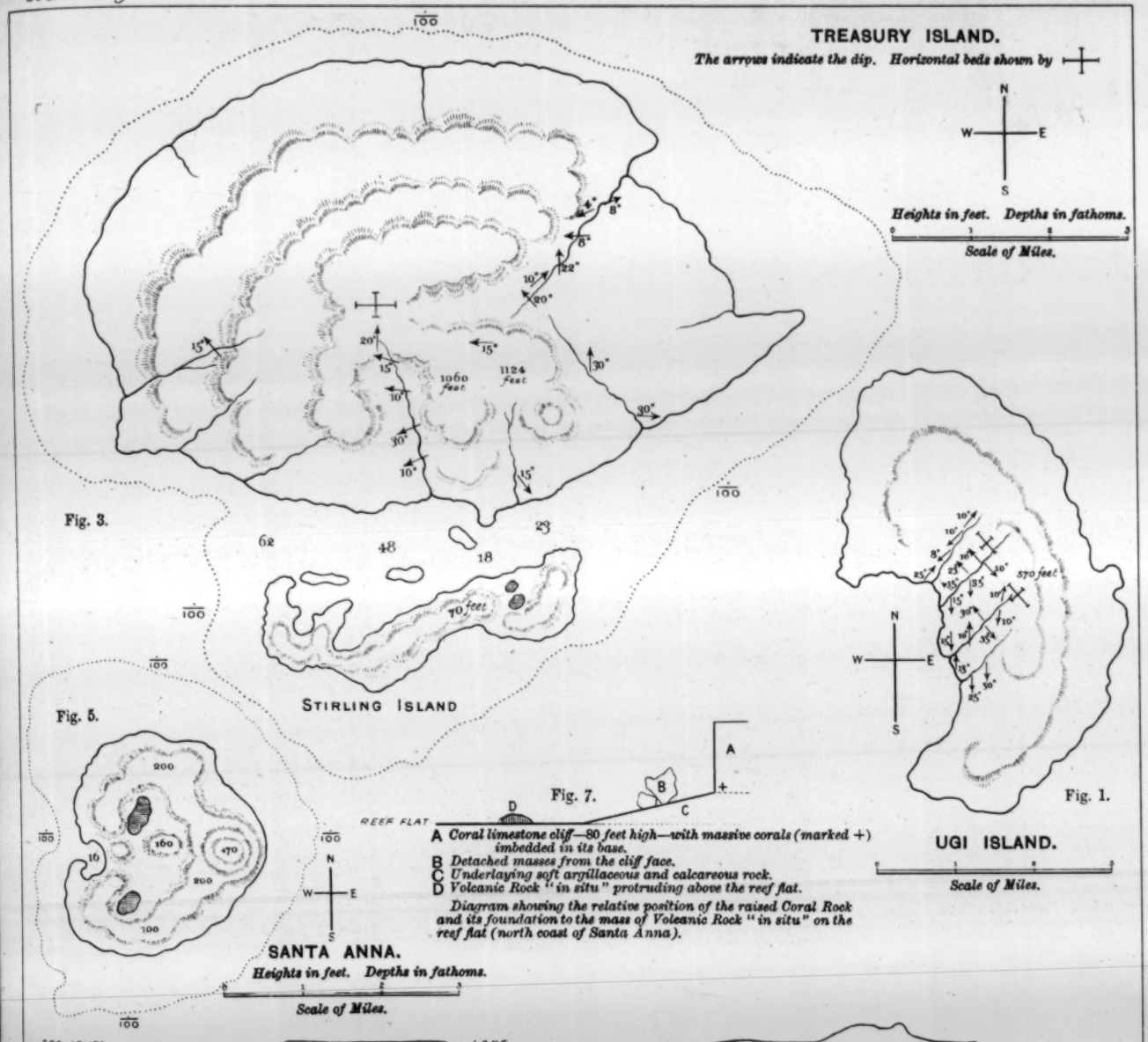


Fig. 3.

Fig. 5.

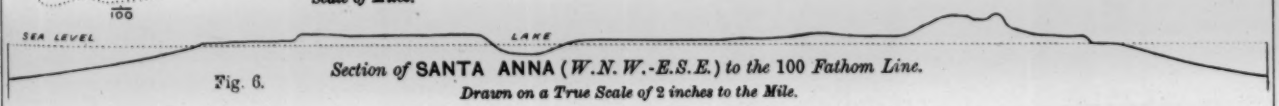
Fig. 7.

A Coral limestone cliff—80 feet high—with massive corals (marked +) imbedded in its base.
B Detached masses from the cliff face.
C Underlaying soft argillaceous and calcareous rock.
D Volcanic Rock "in situ" protruding above the reef flat.

Diagram showing the relative position of the raised Coral Rock and its foundation to the mass of Volcanic Rock "in situ" on the reef flat (north coast of Santa Anna).

Fig. 1.

Fig. 6.



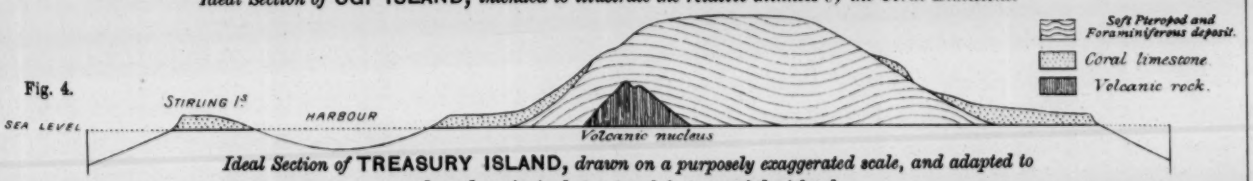
Section of **SANTA ANNA** *(W.N.W.-E.S.E.) to the 100 Fathom Line.*
Drawn on a True Scale of 2 inches to the Mile.

Fig. 2.



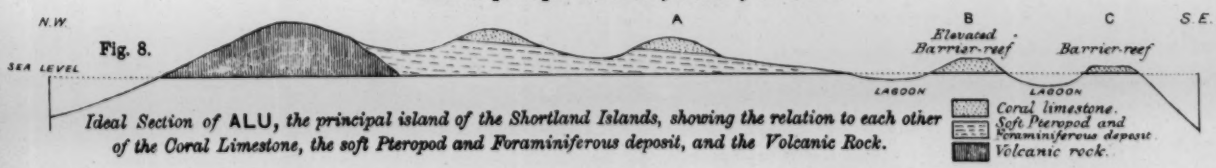
Ideal Section of **UGI ISLAND,** *intended to illustrate the relative thinness of the Coral Limestone.*

Fig. 4.



Ideal Section of **TREASURY ISLAND,** *drawn on a purposely exaggerated scale, and adapted to show the principal structural features of the island.*

Fig. 8.



Ideal Section of **ALU,** *the principal island of the Shortland Islands, showing the relation to each other of the Coral Limestone, the soft Pteropod and Foraminiferous deposit, and the Volcanic Rock.*

McFarlane & Erskine Lith^rs Edin^r

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Fig. 1.



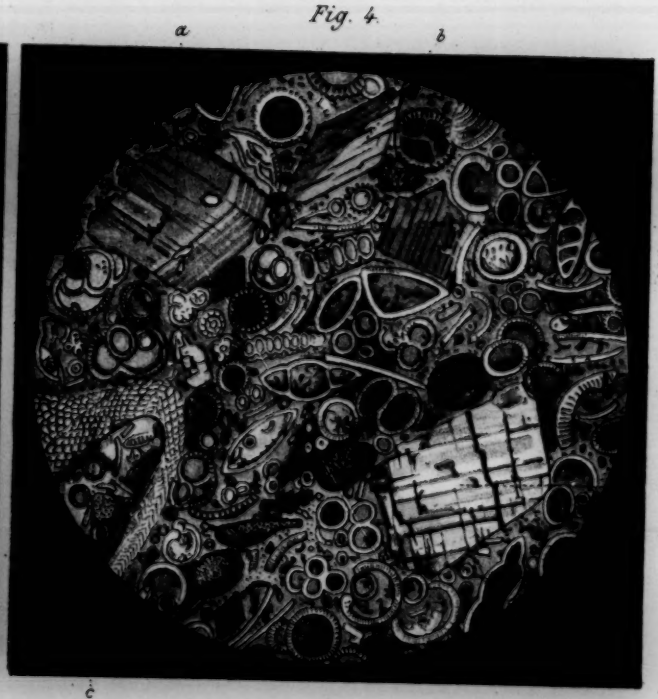
Fig. 2.



Fig. 3.



Fig. 4.



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CALCAREOUS ROCKS OF THE SOLOMON ISLANDS.

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XXXI.—*Observations on Atmospheric Electricity.* By C. Michie Smith. (Pl. CXLVI.)

(Read June 1st, 1885.)

The following observations on atmospheric electricity were made on the top of Dodabetta, between 3rd and 12th January 1885. The position of the electrometer, when not otherwise stated, was at a height of about 5 feet above what remains of the walls of the bungalow formerly used as a meteorological observatory. Dodabetta is the highest hill in the Neilgherries, and the bungalow was built exactly on the top, which is in latitude 11° 24′ 5″·40 N., longitude 76° 46′ 44″·39 E., and at a height of 8642 feet above mean sea-level. The top is free from trees, and my tents were slightly below, and at a sufficient distance off to prevent them interfering in any way with the accuracy of the readings.

The rainfall at the end of 1884 was unusually heavy, and continued till near the end of December, so that mists were very frequent in the afternoons and evenings. These mists usually collected over the hollow in which Coonoor and Wellington are situated, and gradually spread round Dodabetta from about E. by N. to W., and at times remained for hours as a sea of mist, with a nearly horizontal, though of course wavy, upper surface, which reached to within a few hundred feet of the top of the mountain. At times portions would be blown off from the surface of this sea, and would reach the hill-top; but usually, during the day, any mist that reached the top dissolved almost instantly on reaching the warmer air rising up the north-west face of the hill from the valley in which Ootacamund lies. Occasionally, however, the top was completely enveloped in mist, and it was impossible to judge with certainty whether it was a condensing or a dissipating one. Unfortunately I had no hygrometer with me; for, knowing the difficulty of making any satisfactory shade, I thought there was no use of taking one. It is, however, worth noticing that the mists after sunset were, as a rule, very wetting, and were therefore probably condensing.

Turning now to the observations, these are interesting in two ways. First, as regards the daily range and period of maximum strength; and, second, as regards the influence of mist. As it was impossible to carry on observations all night without an assistant, I confined myself to an attempt to get a fairly complete series of readings between 7^h and 20^h (Madras mean time, reckoned from midnight). On half the days readings were taken up to 22^h, and on one night to 24^h. From 6th to 12th January the readings were, with two exceptions, taken hourly from 7^h to 20^h, and a number of intermediate readings were taken, when, owing to the presence of mist or from other circumstances, it seemed likely that they would be of value. In all, above 150 observations were made. The morning readings from 7^h to 13^h were little disturbed by mists, except on the 8th, and the readings for these hours agree

remarkably well with each other, so that the diurnal curve for the forenoon may be considered to represent the true curve very fairly; but this cannot be said for the part for the afternoon hours, for on four days out of the nine the readings have almost no value for determining the normal variation. I have thought it well, however, to give a curve (No. 2, Pl. CXLVI.) showing the mean of all the observations, indicating the number of disturbed readings in each case by a corresponding number of marks on the small circle surrounding the point marking the mean. The curve is drawn from the following means of the readings:—

Hours,	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Readings,	44	49	64	71	84	91	95	99	102	98	114	98	82	95	75	59

The other curve (No. 1) shows the means of the two hourly observations on the 4th, 5th, 6th, 7th, and 9th, which are nearly free from the effects of mists. The following table gives the actual observations on these days :—

Hours,	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January 4,	...	52	...	52	...	75	...	68	...	62	...	64	...	59	...	...	...	...
,, 5,	...	51	...	72	...	125	...	173	170	132	115	91	...	...	73	67	..	...
,, 6,	...	60	65	60	74	78	84	78	68	74	70	75	49	63	...	...	...	...
,, 7.	40	62	66	74	[91]	76	75	92	83	79	64	54	52	[85]	[95]	58	...	...
,, 8,	44	42	72	106	97	115	[142]	[110]	[87]	[84]	[124]	[106]	74	...	90	59	69	62
,, 9,	47	49	65	77	96	111	109	129	125	120	98	60	62	67	56	...	...	...
Mean, omitting the 8th,	...	55	...	67	...	93	...	108	...	93	...	69	...	...	...	...	...	...

N. B.—Those readings within brackets were taken in mist.

If we take this curve as most nearly the true one, we see that there is a well-marked maximum about 14^h M.M.T., and that the curve is fairly symmetrical on the two sides of this maximum for at least four hours; and there is some evidence, though it is by no means conclusive, that the maximum normal readings are obtained at the time of maximum temperature. The observations made do not fix the time of minimum satisfactorily; but probably there are two minima—one early in the morning and another about 19^h, with a small secondary maximum two or three hours afterwards. This diurnal curve differs entirely from that for Madras, which shows a minimum between 9^h and 10^h, and a maximum about 18^h. The average readings at Dodabetta are also much higher than those at Madras; and, as is to be expected, fine-weather readings in Madras are much more variable than those on Dodabetta.

The readings made during the prevalence of mists were begun simply with the object of testing the assertions frequently made, that while all clouds are positively electrified, they are surrounded by a zone negatively electrified. So

far as my observations went, I never obtained indications of negative electricity either in the clouds or round them; but on some occasions I found the positive charge very small, and I was irresistibly led to the conclusion that, on the edge of a *dissolving* mist, the potential was lower than the normal, while in a condensing mist it was higher than the normal. The following table shows the chief readings that were made in mists:—

No.	Date.	Hour.	Reading.	Remarks.
1	Jan. 3	17h 30m	90	Thin driving mist.
2	„ 7	11h	91	Thin mist all round.
3	„ „	20h	85	Thin driving mist.
4	„ „	21h	95	Do. do.
5	„ 8	11h 20m	47	On edge of dissolving mist.
6	„ „	12h	115	Mist all gone.
7	„ „	13h	142	Heavy mist near.
8	„ „	13h 10m	50 to 97	Mist passing in small quantities, and dissolving over brow of hill.
9	„ „	13h 30m	46 to 27	In hollow below tents, more mist.
10	„ „	13h 40m	75	At post pretty thick mist.
11	„ „	13h 50m	22	In hollow mist not so soon dissipated.
12	„ „	14h	110	Post—pretty thick mist.
13	„ „	14h 20m	29	Thick mist all round.
14	„ „	15h	87	Mist all round at a little distance.
15	„ „	16h	84	Clear all round below, cloudy above.
16	„ „	17h	124	Mist all round, and a little driving over the top.
17	„ „	18h	106	Clear. Thin mist below.
18	„ „	19h	74	Clear.
19	„ 9	16h	120	Mist in distance.
20	„ „	16h 40m	49	In hollow—mist drifting past and dissolving.
21	„ „	16h 45m	70	Do. Mist all past.
22	„ 10	15h	73	Overcast.
23	„ „	15h 45m	136	At post thin mist driving past from N.E.
24	„ „	15h 55m	66 to 59	On ridge to N.E. thin mist; just on edge of cloud.
25	„ „	16h	73	Very constant—little mist.
26	„ „	17h	160 to 128	Mist all round.
27	„ „	17h 30m	133 to 145	In pretty thick mist.
28	„ „	18h	153	In thick mist.
29	„ „	19h	100	Clear. Clouds on horizon, and a little sheet lightning on clouds below.
30	„ „	28h	82	
31	„ „	16h	150	Thick mist all round, and drifting over the top.
32	„ „	16h 20m	137	Still thick mist.
33	„ 11	17h	177	Thick mist.
34	„ „	to	125	Break in mist.
35	„ „	17h 5m	166	Mist on again.
36	„ „	18h	155 to 162	Thick mist.
37	„ „	19h	109	Mist.
38	„ „	20h	149	Dense mist.

Before discussing these it is necessary to note that when the observations were not made at the "post" they were made at places where I found that in fine weather I got readings very nearly the same as those got at the post. It is not necessary to go over the whole table. A few of the more marked cases will sufficiently illustrate the main features.

No. 6 at 11^h 20^m the reading on the edge of a dissolving mist was 47, while the average for that hour is about 87.

No. 8 shows small quantities of mist passing and dissolving, and the readings varying from 50 to 97. The normal reading for this time being about 90.

No. 9. This reading was taken at some distance from the post as the mist was drifting up a ravine to the west, and I stood so as to be just in the mist. The readings were very low—46 to 27.

No. 11, taken at the same place as No. 9, gave a reading of 22. The mist was then thicker, and so went farther before it was completely dissipated, but it was clearly a dissolving mist.

No. 13 is a doubtful case, as the mist was all round, but as it cleared off soon after it was probably even then dissolving.

Nos. 20 and 24 are very clear cases.

No. 26. Here the readings are from 160 to 128 when the normal was about 93. This mist was a very wetting one.

Nos. 27 and 28 are also far above the average.

Nos. 31 to 38 were all in thick condensing mists, and in each case the readings are far above the average. I may add that I purposely avoided examining the observations in detail at the time, and simply recorded as many as possible. It should be noted, too, that in heavy wet mists the readings may at times be too low, as the ebonite which insulates the wire in communication with the inside of the electrometer is apt to get moist in spite of the umbrella. This difficulty is got over by using a match which burns quickly, and by seeing that the ebonite is quite dry before each observation. With a slow burning match I found the results quite untrustworthy.

The observations detailed above are by no means conclusive evidence of the theory that I have ventured to draw from them, but they are sufficient to show the importance of a much more careful examination of the electrical state of condensing and dissipating mists. Such observations would be of great value in connection with the discussion of the cause of thunderstorms, and if my results are confirmed by more extended observations strong support will be given to the theory which looks on the condensation of a number of slightly charged particles into large drops as the cause of the high potential indicated by disruptive discharges. It has been suggested as an explanation of some of my observations that every cloud is surrounded by a zone at a lower potential

than the cloud, but a careful study of the observations will show that this is not quite an accurate statement of the case, as some of the observations show a high potential outside, but near a thick mist. Of course most clouds are dissipating at the outside, so that a low potential will, if I am right, be usually found there.

It seems worth pointing out that, if we neglect the readings made in mist, the highest were got on the 5th, when it was almost perfectly calm and there was a thin but very decided haze. The temperatures during the day were also above the average.

The electrometer used throughout my observations was Thomson's small portable electrometer, No. 43, which gives a reading of about 24 divisions for 100 Daniell cells, when tested at a temperature of about 90° F. I find, however, that there is a large temperature effect on the zero readings, and I have not been able to test whether or not this affects the value of the scale readings. In Madras the leakage is so great and the temperature range so small that I could never be quite sure of the effect of temperature on the zero reading, but it was different in the comparatively dry atmosphere of Dodabetta, where the instrument retained its charge well and where it was used in temperatures varying from about 38° to 69° in the shade, but really with a much wider range since the day observations were made in the sun, in which a black bulb thermometer rose to from 125° to 138°. The accompanying curve (Pl. CXLVI.) shows the changes in the zero readings during four days, and an approximate curve for the shade temperatures during the same period. The temperatures are only a very rough approximation, as during the time that the sun was above the horizon they were taken between the outer and inner walls of the tent near the door, on the side away from the sun, no better shade being available; at night the thermometer was placed outside 4 feet from the ground.* It will be seen from these curves that on the 8th the zero rose from 1202 at 14^h to 1261 at 23^h a rise of nearly 5 per cent. At first this large temperature change gave me considerable trouble, as I found that the earth readings before and after the air reading differed considerably from each other, but this difficulty was reduced to a minimum by leaving the electrometer on the observing post for a few minutes before making the observation. It will be

* The minimum thermometer gave readings varying from 32°·5 on the 7th to 40° on the 5th and 6th, with an average of 36°. It is interesting to compare this with the reading made in the Dodabetta observatory, and I have accordingly taken the observations for the five years from 1848 to 1852 for the corresponding days of January. I find the lowest recorded temperature is 40°·4, while the average is 45°·1, or 9° higher than the average which I got. Only a small part of this difference can be ascribed to the unknown error of the thermometer used then, and it is equally improbable that the present year was so much colder than any of the years during which the observations were made. The only remaining explanation is that, as popularly believed, the observer took his thermometers inside the hut that so he might escape the necessity of going out into the cold mist-laden air after nightfall.

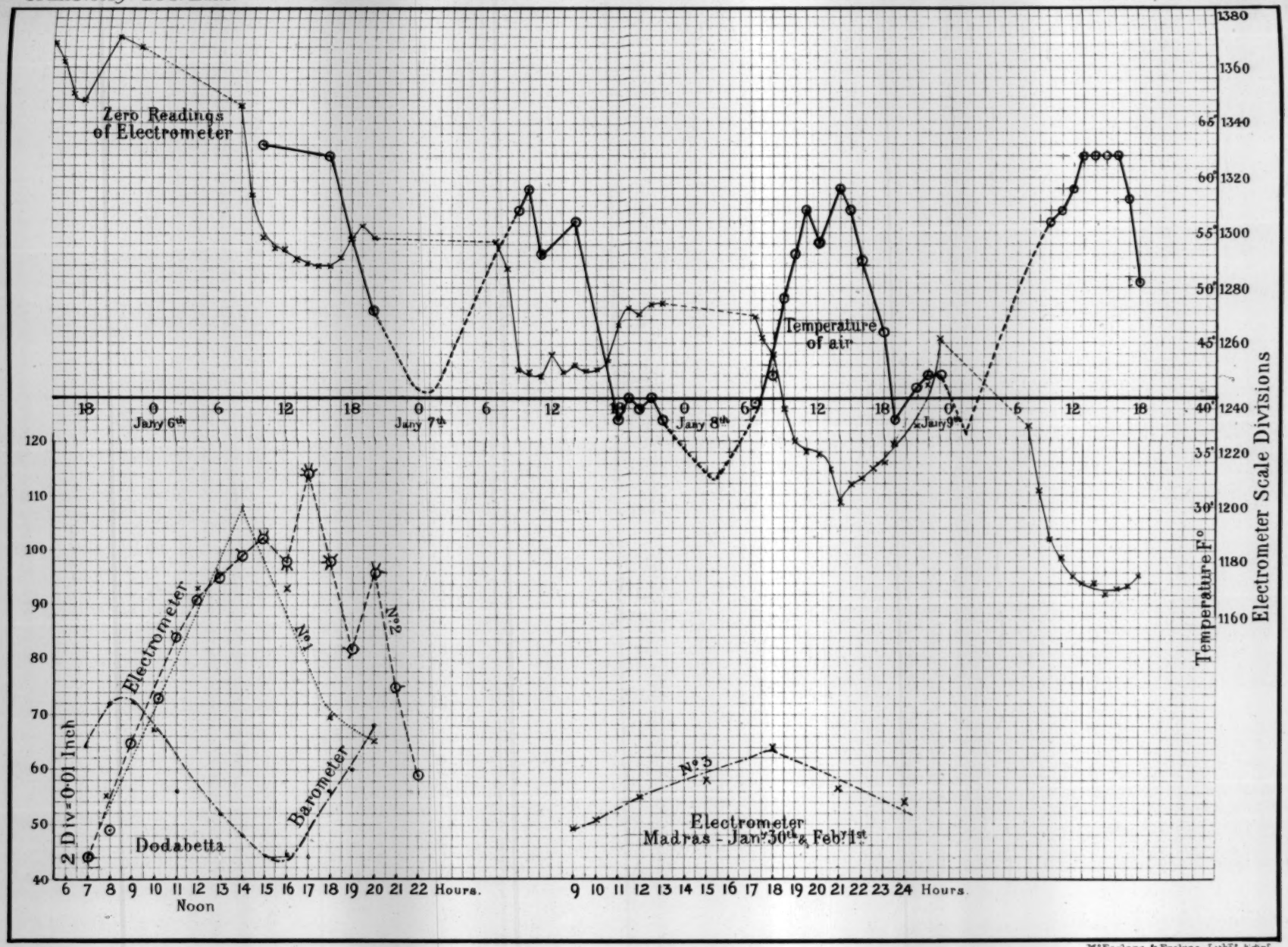
noticed that the temperature error is in the opposite direction to that usually found in these instruments, though Sir WILLIAM THOMSON has found * one (White, No. 18) which showed an error in the same direction.

The above observations were rendered possible by the kindness of His Excellency the Right Honourable M. E. GRANT DUFF, who placed tents at my disposal, and of Mr L. R. BURROWS and Mr D. HOOPER, who gave me valuable assistance.

* *Electrostatics and Magnetism*, p. 301.

MADRAS, 22*nd April* 1885.

Trans. Roy. Soc. Edin. Vol. XXXII, Plate CXLVI.



M.cFarlane & Erskine, Lith.rs Edin.r

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XXXII.—*Note on Ectocarpus.* By JOHN RATTRAY, M.A., B.Sc., Scottish Marine Station, Granton, Edinburgh. Communicated by JOHN MURRAY, Esq., Ph.D. (Plates CXLVII., CXLVIII.)

(Read 2nd February 1885.)

The group of the Phæosporeæ was first recognised by THURET * in 1850. It includes algæ that vary greatly in size, habit, external appearance, and mode of branching, some possessing a flat thalloid appearance with or without a long stalk (*e.g.*, *Laminariæ*), others being filamentous and much branched (*e.g.*, *Ectocarpus*, *Sphacelaria*, *Chordaria*, &c.). The great majority of the genera included in the group are marine or brackish water forms, but recently E. FLAHAULT † has described, under the name of *Lithoderma fontanum*, a fresh water species from the neighbourhood of Montpellier.

All the forms included under the genus Ectocarpus are filamentous, and usually much branched, *E. crinitus* being one of the simplest types, and *E. siliculosus* one of the most complex. The primary branches again may be straight or present gentle undulations (*e.g.*, *E. siliculosus*), or may exhibit well-marked geniculations at the points of origin of the ramuli (*e.g.*, *E. distortus* and *E. Landsburgii*). In some the central filament is of greater diameter than the secondary branches, and so remains a prominent feature in the plant, but in others this occurs to a much less degree, both being of approximately equal size (*e.g.*, *E. crinitus*, &c.).

The particular zone in which the Ectocarpi flourish is that extending from high to low water mark, some being found over the whole bathymetrical extent of this belt (*e.g.*, *E. brachiatus*, *E. tomentosus*, *E. littoralis*, *E. siliculosus*, *E. sphærophorus*), others occurring chiefly at the level of half tide (*e.g.*, *E. crinitus*), while yet others are especially obtained near that of low water (*e.g.*, *E. fasciculatus*). Their mode of attachment, too, varies very greatly. They are to be found adhering to mud-covered rocks and stones in the shade (*e.g.*, *E. crinitus*) or in exposed situations (*e.g.*, *E. littoralis*), as well as epiphytically on other algæ in shaded pools (*e.g.*, *E. brachiatus*), or in open places (*e.g.*, *E. sphærophorus*).

The great majority of the species of this genus are found to grow epiphytically on other seaweeds, some being apparently confined to a limited number of host plants, others being less restricted in this respect. Thus *E. brachiatus* is only found associated with *Rhodymenia palmata*, just as *Polysiphonia fastigiata* almost exclusively occurs on *Ascophyllum nodosum*, while *E. fasciculatus* and *E.*

* Thuret, "Recherches sur les zoospores des Algues," *Ann. des Sci. Nat.*, series iii. vol. xiv. 1850.

† *Comptes Rendus*, xcviii. (1884), pp. 1389–91.

tesselatus chiefly occur on *Laminaria digitata* and *L. saccharina*. On the other hand, the host plants of *E. littoralis* and *E. siliculosus* are very numerous, the latter, up to the present time, having been found on *Cladophora rupestris*, *Corallina officinalis*, *Chorda lomentaria*, *Chordaria flagelliformis*, *Ceramium Deslongchampsii*, *Asperococcus echinatus*, *Halidrys siliquosa*, *Polysiphonia elongata*, *P. urceolata*, *Myriotrichia clavæformis*, and *Rhodymenia palmata*, in the Firth of Forth.* Next to *E. siliculosus* and *E. littoralis*, *E. sphærophorus* is that which is least restricted in its range of host plants, being chiefly found associated with Rhodosperms (*e.g.*, Callithamnia and Ptilotæ). From this peculiar habit the entire genus might be conveniently divided into two groups —a smaller containing the non-epiphytic species, and a larger including all those found growing on other algæ.

Ectocarpus siliculosus (Lyngb.), upon which my present observations are founded, is an annual plant occurring chiefly from May to September, or, according to HARVEY,† from "spring to autumn." As already indicated, this species is found between the highest and lowest limits of the tide, and even extends to depths varying from three to four fathoms.

In general habit *E. siliculosus* is most closely allied to *E. littoralis*, but may be distinguished from the latter by its more slender and somewhat softer growth, and by the fact that its ramuli, which may be either alternate or subsecund, are never opposite—an arrangement which may occur in young branches of *E. littoralis*. The multilocular sporangia, moreover, of the two species may be readily distinguished, those of *E. littoralis* being placed in the middle of the ramuli, while those of *E. siliculosus* are lanceolate and terminal.

In addition to the ordinary multilocular sporangia (=Trichosporangia, Nob.) upon whose true reproductive significance all observers are agreed, various species of Ectocarpus have from time to time been found to possess so-called "unilocular sporangia" (=Oosporangia, Nob.) with regard to which there has not been the same consensus of opinion among algologists.

THURET,‡ when discussing the fructification of the Phæosporeæ, says :—"La seule fructification que l'on signale dans ces plantes consiste en sporanges ovoïdes (Oosporangia, Nob.), qui ont d'ailleurs été toujours décrits comme des spores simples, quoique en réalité ils soient remplis de nombreux zoospores. Cet organe est le plus visible, et c'est ce qui explique pourquoi il a surtout attiré l'attention des observateurs. L'autre forme de sporanges consiste en filaments cloisonnés.

"(Trichosporangia, Nob.), fort étroits et généralement assez courts, composés d'une séries de petites cellules, dans chacune desquelles est renferné un zoospore.

* Traill, *Monograph of the Algæ of the Firth of Forth*, 1885.

† Harvey, *Phycologia Britannica*.

‡ Thuret, *loc. cit.*, pp. 235–236.

Ces filaments sont tres nombreux, et occupent la même place que les sporanges ovoïdes, qu'ils accompagnent parfois: plus ordinairement néanmoins, on ne trouve á la même époque que l'une ou l'autre forme de fructification sur le même individu. Les zoospores issus de ces deux organes offrent une parfaite ressemblance. Seulement ceux qui proviennent des sporanges filamenteux sont un peu plus grands que ceux qui s'echappent des sporanges ovoïdes. J'ai vu d'ailleurs germer les uns el les autres, ce qui prouve suffisament leur compléte identité."

J. E. Areschoug * finds "Oosporangia" and Trichosporangia in *Ectocarpus littoralis*, Harv., and in *E. fasciculatus*, Harv.

J. G. Agardh † describes the fruits of Ectocarpus as consisting of (1) spherical or ovate sessile sporæ or sporidia, enclosed within a hyaline perisporium, and (2) of motile sporidia—the sporidia being spherical or ovato-ellipsoidal capsules. He also describes pod-like propagula.

Kützing ‡ figures in *Ectocarpus fasciculatus* unilocular forms of fruit as "spores," and multilocular as "spermatoidia," the latter, according to Professor Perceval Wright, being very like parasitic Chytridial growths. He also represents, according to Professor Magnus, Chytridial parasites as "intercellular spores" of various Callithamnia.

C. Gobi § figures "Oosporangia" and Trichosporangia in *Ectocarpus approximatus* v. *balticus*, Kütz.

W. G. Farlow ‖ notes that the so-called "oosporangial" fruit of Ectocarpus has not hitherto been observed in America, although the trichosporangial form is well known.

Harvey,¶ as pointed out by Professor Wright, represents the round or elliptical sessile "utricles" or "spores," which have been recognised as "oosporangia," as outgrowths of cells in *Ectocarpus crinitus*, *E. pusillus*, *E. granulosus*, and *E. sphærophorus*.

Pringsheim,** while figuring (Taf. ix. fig. 7) the terminal portion of a branch of *Sphacelaria olivacea* v. *cæspitosa*, Dillw., which has become invaded by parasitic Chytridial cells, also represents (Taf. ix. fig. 9, *c*) certain cells which have enlarged into a rounded ball-shaped form, which he calls "Brutzelle," but the exact interpretation of these structures he leaves undecided. "Die sonder-

* J. E. Areschoug, *Algæ Scandinavicæ exsiccatæ, serei novæ*, Feb. 4, 1862.

† J. G. Agardh, *Species, Genera, et Ordines Fucoidearum*, Lundæ, 1848, p. 14.

‡ Kützing, *Tab. Phyc.*, vol. v. pl. 50, ii.

§ C. Gobi, "Die Brauntange des Finnischen Meerbusens," *Mem. de l'Acad. Imp. des Sci. de Petersbourg*, sept. serie, tome xxi. No. 9, 1874.

‖ W. G. Farlow, "List of the Marine Algæ of the United States," in *Proc. Amer. Acad. of Arts and Sciences*, vol. x. 2nd series, p. 351, 1875.

¶ Harvey, *loc. cit.*

** Pringsheim, "Ueber den Gang der morphologischen Differenzirung in der Sphacelarien-Reihe.," *Abhandl. d. Konigl. Akad. der Wiss. zu Berlin*, 1873.

bare Umwandlung ihres Inhaltes, die sich von der der endständigen Sphacelen wesentlich unterscheidet, *gestattet noch keine sichere Deutung.* Entschiedene Parasiten sind mir in ihnen nicht aufgefallen. Es ist mir nicht fraglich, dass es diese Bildungen sind, welche einige ältere Algologen als sitzende Sporen beschrieben und abgelildet haben."

The parasitic or non-parasitic nature of the much swollen club-shaped cells represented in plate ix. fig. 9, *d*, and in plate x. figs. 5, 6, and 7, the contents of which escape as free swimming ciliated swarmspores, a more or less definitely defined network of the mother cell walls being left behind, this author also leaves undecided, remarking—"Ich habe diese Bildung, die sich, wenn sie nicht in den Entwickelungsgang der Pflanze selbst gehört, an keine bekanntere Parasitenform anschliesst, bisher nur an der *Sphacelaria olivacea* von Helgoland aufgefunden; an anderen Sphacelarien ist sie mir nicht aufgestossen. Sie verlangt eine weitere, eingehende Berücksichtigung."

Cohn,* in 1867, drew attention to the fact that Chytridial parasitic organisms had often been represented as part of the tissue proper of the host plants, *e.g.*, by Solier and Derbés,† in the case of *Aglaophyllum ocellatum*, while Magnus refers the "abnormally swollen up apical cells in *Ceramium spiniferum*, Kütz., figured by Cramer, to a new species of Chytridium—*Olpidium tumefaciens*, Mag.,‡ which is figured by Harvey § as probably the antheridia of *Callithamnion dispar*, Harv.; he also believes that the "abortive spore mother cells," figured by Nägeli ‖ in *Callithamnion cruciatum*, are referable to the parasitic *Chytridium plumulæ*, Cohn.

Professor E. P. Wright ¶ maintains that Grunow** has taken parasitic Chytridia for true spores in *Callithamnion*, and possibly in *Leda capensis* (Grun.), &c.

In *Ectocarpus granulosus*, Professor Wright "has watched through all its stages, save that of germination, the Chytridial form which has been mistaken for an oosporangium," and while satisfying himself that the parasite is the "only fruit known" in *Ectocarpus crinitus*, he believes that in *E. sphærophorus* the oval cells, although they may not be foreign bodies, are "most suspiciously like some Chytridial growth."

* F. Cohn, "Beiträge zur Physiologie der Florideen," Max Schultze's *Archiv für Mikroskopische Anatomie*, Bd. iii. s. 41, 1867.

† Capt. Solier and Dr Derbés, *Memoire sur la Physiologie des Algues*, p. 67, pl. xxi. figs. 10–12.

‡ Magnus, in *Jahrbericht der Commission zur wissenschaftlichen Untersuchung der deutschen Meere in Keil*, fur die Jahre 1872–73, Berlin, 1875.

§ Harvey's *Phycologia Australica*, vol. vi. 1862.

‖ Nägeli, *Die neuern Algensystem*, Zurich, 1847, p. 202, Tab. vi. fig. 1, *s*, *s*; 4, *s*, *s*.

¶ Prof. E. P. Wright "On a Species of Rhizophydium parasitic on Species of Ectocarpus, &c." *Trans. Roy. Irish. Acad.*, vol. xxvi. August 1877.

** Grunow, *Reise S. M. F. Novara um die Erde. Botanik*, Th. i. Algen, Tab. vi.

The genus Rhizophydium was established by SCHENK for Chytridiaceous parasites, whose spores escape by one or more apertures. The globular and unicellular *Rhizophydium Dicksonii* has hitherto only been noted on *Ectocarpus granulosus* gathered at Howth, near Dublin, during the winters of 1876 and 1877. I, however, gathered specimens of *Ectocarpus siliculosus* which were affected with this parasite on December 4, 1884, about 10.30 A.M. The host plant was found growing epiphytically on a fragment of *Polysiphonia fibrillosa*, which was obtained about the level of $\frac{3}{4}$-tide in the old Granton Quarry. A small part of the shale on which the *Polysiphonia* grew was removed at the same time, so that the epiphyte and its parasite were disturbed as little as possible. The temperature of the water at the time of removal was 41°·2 Fahr. Some of the specimens of Ectocarpus thus obtained were placed in a small glass vessel containing sea water, and kept for some days in the microscopic room of the "Ark," the floating laboratory connected with this station. This material was repeatedly examined to determine when rupture of the cells would be likely to take place, and this occurred about 1.30 P.M. on December 7, when specimens were at once mounted in weak acetic acid. The temperature of the water in the vessel in which rupture occurred was 51°·8 Fahr.

The parasitic Rhizophydial cells were found to be widely disposed over the penultimate, but sometimes occurred on the ultimate ramuli of their host plant (Pl. CXLVII.). In the former they were not confined to any definite region, but were found scattered at irregular intervals along their entire length. They usually occurred singly, but at other times were found in pairs (Pl. CXLVIII. fig. 8), while in a few cases three contiguous host cells were attacked (Pl. CXLVIII. fig. 3).

The parasitic cells enter the cells of the host plant at a very early stage of their existence, and gradually develop at the expense of the highly organised protoplasmic contents of the latter. In Pl. CXLVIII. fig. 2, two adjoining host cells have been penetrated by the Rhizophydial cells, which have arrived at different stages of development; Pl. CXLVIII. fig. 2, *a*, represents the earliest stage which I have observed. The parasite presents the appearance of a nucleus, and is surrounded by a thin but definite cell wall. In figs. 1, 4, and 5 of the same Plate somewhat more advanced stages of development are represented, and while in figs. 1 and 5 the Rhizophydium has assumed an almost perfectly ellipsoidal form, in fig. 4 it exhibits a tendency to expand laterally, being even slightly involuted at one end, on account of the greater resistance to which it is exposed in this region. At this stage the presence of the parasite is, in ordinary circumstances, revealed by the slightly globular form assumed at a very early period by the host cell containing it. Sometimes, however, as in the case represented in fig. 2, *b*, the parasitic cell may grow to a moderate size without producing the ovoid bulging of its containing host cell, and without itself retaining the normal globular or ellipsoidal outline. This is probably attributable to the

fact that it has entered a cell which is not very rich in organic contents, in which it is enabled to develop without producing so great internal pressure as must necessarily be exerted when the latter is tensely filled with fluid cell sap and other protoplasmic substances, or derivatives from these.

A still more remarkable appearance is that represented in fig. 6. Here the host cell has become distinctly globular, and contains a well-defined parasitic Rhizophydium, around which a more or less hyaline area is found, in which the chlorophyll granules show manifest pathological changes. Instead of being absolutely round, this parasite has a well-defined and moderately deep indentation on one margin, around which its cell wall passes without interruption. It is not easy to give a satisfactory reason for the existence of this fold, although two possible explanations may be offered, namely, it may be due to the existence of a greater internal pressure existing in the host cell at this point, a slight divergence from the perfect equilibrium being sufficient to cause a sinuosity in the thin and pliant cell membrane, or if this parasite should ultimately be found to possess this indentation in its earlier stages, it may point to a specific distinction between it and the perfectly ovoid or globular type. As only a single instance of this peculiar phenomenon was observed, it is not unlikely that the former explanation is the more trustworthy.

At the moment of rupture the cells containing the mature Rhizophydia present in most cases a distinctly ovoid appearance. That the internal tension in these cells is at this time great is proved at once by their external form, by the fact that they bulge into adjoining cells of the host plant which are not so affected, and by the existence of creases which may not uncommonly be observed just after the rupture (fig. 12). It is also to be noted, that as soon as relief from this tension is obtained, the adjoining cells of the thallus of the host plant at once become convex on the side of the ruptured cell in virtue of their own elasticity, and so tend to cause a more violent rupture, and to facilitate the dissemination of the swarmspores of the parasite.

In cases where three adjoining cells contain parasites (fig. 3, *a*, *b*, *c*), the middle cell, which is unable to indent the walls of the adjoining tense cells, expands usually in a somewhat lateral direction, and always towards that side on which the resistance is least when this tendency is first manifested.

After rupture takes place the appearances presented by the affected cell areas are sometimes of a very fantastic kind. The cell wall of the parasite, as soon as the wall of the host cell opens, suddenly swells up, owing to the pressure exerted by the contents against its inner surface, in many cases to twice its former dimensions (figs. 7, 10, 11, &c.). At first the parasitic cell membrane is entire (fig. 10), but it soon opens to the exterior, sometimes by a single pore (fig. 9), which may be directed either towards the base of the filament, or towards its apex, or at right angles to its longitudinal axis, sometimes by two

pores, the one being directed towards the base of the filament, the other towards its apex (fig. 8, *a*), or both being placed approximately at right angles to its axis, either on opposite sides (fig. 8, *c*), or on the same side, at other times by three apertures arranged in various ways (figs. 11, *a*, and 12). It should here be noted that these apertures in the cell wall of the parasite often lie in different planes, and that it is not always possible to see all of them without a change of focus under the microscope.

Although two or three openings are of frequent occurrence in the cell membrane of the parasite, the cell wall of the host plant invariably opens only at one point, and in many cases it is possible to see clearly the margins of the ruptured wall (figs. 7, 9, 10, and 11). It may also be observed, that this ovoid wall is no longer able to recover its original form after rupture, inasmuch as the limit of its elasticity has in most cases been passed, so that a perfect rebound is not possible, while the long continued internal tension has contributed to it a certain fixity of form which its remaining elasticity is not able to reverse.

In some cases (fig. 9) one meets with a remarkable involution of the wall of the host cell after rupture has occurred. This fold, which usually occupies a position approximately diametrically opposite to the place of rupture, may have resulted either from the fact that the cellulose wall burst before the limit of its elasticity was passed, so that a sudden and sharp recoil became possible, or from the impact of some foreign body which, by striking against the involuted region, at once caused that fold, and affected a rupture of the wall at the diametrically opposite point. The occurrence of such a fold is, however, unusual.

After rupture the swollen cell membrane of the parasite, which invariably remains very thin and pliable, exhibits numerous creases, which become especially manifest when examined under a water immersion high power lens (fig. 7). These fine irregular folds point to the presence of a certain amount of rigidity in this membrane, which may be partly induced by direct contact with the water of the surrounding medium. That the immense surface which the intact but swollen host-cell membrane offers to the waves must tend powerfully to bring about the complete destruction of the host plant by inducing or effecting complete breakages of the thallus at these already weakened regions is at once obvious.

When the parasitic cells have just opened, relief from internal tension is at first experienced in the neighbourhood of the orifice or orifices, and it is often possible to observe that the young swarmspores, into which the protoplasm has divided, and which lie toward the opposite side of the cell, have, at this time, an angulated or polyhedral outline. This, however, is of a transitory character, and is due to the mutual pressure resulting from their continued growth (fig. 11, *a*).

A peculiar and interesting disposition of the swarmspores is to be observed

in fig. 10. Here the host cell wall has ruptured, and the membrane of the parasitic cell has swollen so much that a complete relief from internal pressure has occurred without rupturing the latter. The result is that the smarmspores are arranged in a retiform manner, forming meshes by adhering to each other along certain lines. That this is a transitory stage is at once manifest, but that it may be the final appearance, presented by the swarmspores generally just before the rupture of their bounding cell membrane takes place, is not unlikely. It indicates that, although the protoplasm contained in the parent Rhizophydium divides by a simultaneous process into numerous spores, a final separation is not effected at the same moment throughout the entire mass, but rather along certain lines whose direction is in all probability determined by the lines along which the force or forces that determine rupture act.

Various causes operate in bringing about the rupture of the cell wall of the host plant, as well as of the thinner and more elastic membrane of the endo-parasite. These may be regarded as being (*a*) intrinsic and (*b*) extrinsic. Of intrinsic causes there may be noted (1) internal tension, and (2) weakness resulting from pathological changes. The former of these factors is no doubt that of the greater significance. It originates in the developmental changes that take place inside the endo-parasite. The volume of the latter is being slowly increased, and while a certain amount of nutritive material must be removed from the host cell to produce this result, so that tension strain would thus so far be antagonised, the growth of the parasite that follows more than counterbalances the changes effected, while at the same time a certain amount of carbonic acid gas, resulting from protoplasmic oxidation, given out by the parasite, will tend still further to increase the pressure. As already noted, that pressure causes, first a bulging of the host cell into the surrounding medium chiefly, but also partly into adjoining cells of the thallus when these are not similarly affected, and finally it results in producing rupture at their weakest point. The ultimate expansion and rupture of the parasitic cell wall are due to a similar tension exerted by the ever-increasing swarmspores.

(2) The weakness resulting from pathological changes, operates, though in a less degree, in accelerating the bursting of the host cell wall. The full complement of nutritive material no longer reaches this wall from its normal channel, viz., its own cell protoplasm, so that the supply of new food molecules, to maintain the oxidation consequent on vital activity, is partially checked. This may result in pathological molecular transformations in the wall, producing areas of weakness, where rupture becomes possible by the operation of internal pressure and the other extrinsic causes. In confirmation of this view, it is to be remarked that the host cell is not usually found to rupture at or towards an angle of the cell,* but, in most cases, opposite the middle of the cell lumen.

* If rupture occurs here, it is attributable to the action of extrinsic and purely accidental causes.

This is explicable on the supposition that the parts of the cell wall adjoining other cells continue to receive relays of food molecules from the latter, when they are no longer able to procure them from the protoplasmic material which occupies the lumen of the cell which they themselves bound, so that devitalising changes are retarded most, just in the immediate vicinity of these adjoining cells, but less and less as we advance from that point, and least of all opposite the middle of the cell lumen where rupture is effected.

Among the extrinsic causes that induce rupture, there may be noted (1) the pressure exerted by the contents of adjoining cells which are not similarly affected with the parasite. The operation of this cause becomes plain when it is remembered that the bulging of the affected cell causes the cell walls, bounding adjoining cells, to become concave on the side next itself. This sets up an elastic pressure in the contents of these adjoining cells, which in turn acts on cells next them, and so on. When rupture of the ovoid host cell takes place, the hitherto concave walls of the neighbouring cells become convex, and so bulge into the ruptured cell, thereby causing a wider dissemination of its contents than would otherwise be the case.

(2) The impact of ripples or foreign bodies against the swollen host cells, the former of which especially occurs when the tide just reaches the level at which the plant grows, have obviously a similar tendency.

Negative heliotropism of the swarmspores of Rhizophydium.—After a large number of the swarmspores of Rhizophydium had escaped into the watch-glass in which the host plants lay, the glass was surrounded, to the level of its brim, with black paper, so that no light could penetrate into it from beneath. The surface was then covered as closely as possible to the level of the water with a similar piece of black paper. Before being covered on the surface, the water in the glass was stirred gently with a needle, so that the swarmspores were equally diffused through it. The cover when adjusted was allowed to remain for several hours, and it was so arranged as to conceal the surface of fully three-fourths of the glass. On re-examination of the water by removing two samples of it simultaneously with two very small dipping tubes, and placing them under microscopes, it was found that while the water which had been exposed to the daylight contained a few swarmspores, the greater number of the spores, which were still in active motion, had congregated on the dark edge of the glass. Their general tendency must, accordingly, be regarded as negatively heliotropic.

In connection with this subject, it may at this point be noted, that in the same gathering of *Ectocarpus siliculosus*, many specimens were obtained which bore the ordinary multilocular fruit figured by HARVEY.* The biciliate swarmspores that escaped were observed for some hours under the microscope. The

* Harvey, *Phyc. Brit.*

light was so adjusted, by means of the mirror, that about two-thirds of the field was dark, while the remaining third was illuminated with diffuse daylight, and it was observed that the true reproductive swarmspores of this species had similar negative heliotropic tendencies, as they congregated on the dark part of the field.* In a genus closely allied to Ectocarpus, viz., *Sphacelaria plumigera*, I am informed by Mr TRAILL that Mr E. M. HOLMES, F.L.S., has recorded similar heliophobic movements of the swarmspores. It may be added, by way of contrast, that, according to BORZI,† the zoogonidia of Ulva are positively heliotropic, while the conjugated zoospores have opposite or heliophobic tendencies.

The significance of such movements, in relation to the light, may be of importance as affording an early indication of the habit of the plants. Thus many marine algæ avoid exposed sunny places, and delight in dark rocky crannies, where the rocks, from their softer nature, have become eroded by wave action, aided by the denudatory effects of the impact of hail, snow, rain, &c. That such seaweeds tend to accelerate marine erosion cannot be doubted, when it is remembered that their rhizoids, in many cases, become entangled among minute particles of shale or other soft rock, and that the plants possess a certain buoyant power which tends to lift the fragments, to which these rhizoids are fixed, from their place. This buoyant power, moreover, is often largely increased by the passage of waves which play against the thallus, and so increase its pull upon the rock to which it is fixed.

Although swarmspores, that are thus heliophobic, tend in the first instance to settle down upon shaded water-worn spots, it does not follow that round mammillated or exposed rocks are never covered by algæ, whose spores exhibit such a tendency. It is to be borne in mind, on the contrary, that a heliophobic spore may often find enough of shade among the rhizoids of other pre-existing weeds, while its rhizoids will in turn form a suitable nidus for another similarly disposed spore, so that finally a round exposed protuberance may be entirely covered with algæ whose spores are negatively heliotropic.

In connection with what has been stated above, with regard to the escape of the multilocular swarmspores of *Ectocarpus siliculosus*, it is of interest to record that the period during which spores may escape in that species can no longer be limited to the summer season, as has hitherto been done in the basin of the Firth of Forth, but must be extended to December. It is, however, to be borne in mind, that the unusual mildness of the season, combined with the sheltered locality in which the specimens were found, may have largely contributed to this result. It is also worthy of remark, that a rise of temperature has a direct influence in hastening the escape of the swarmspores, inasmuch as specimens

* In this case direct rays of light were carefully excluded from the stage of the microscope.

† Borzi, *Studi algologici*, 117 pp. (9 pl.). Messina, 1883.

from the same gathering, which were kept in a somewhat colder part of the "Ark," did not discharge them so soon as others which were placed in the microscopic room, which was kept at a higher temperature.

It is, moreover, interesting to observe, that although the septa across the multilocular sporangia of *Ectocarpus siliculosus* usually persist, yet it sometimes happens that these septa disappear before maturation of the spores, in which case the sporangium becomes ultimately unilocular.

This observation corroborates the statements made by PRINGSHEIM * with regard to *Ectocarpus siliculosus* and *E. granulosus*, whose general conclusion is stated as follows:—"Diese Beobachtungen führen zu dem Schlusse, dass die Differenz der beiden Sporangienformen der Phæosporien, die sich in der fehlenden oder vorhandenen Fächerung ausspricht, keine absolute ist, sondern nur einen verschiedenen Grad der Ausbildüng und Persistenz oder Resorption des transitorischen Mutterzellgewebes der Schwärmsporen ausdrückt. Bei den Oosporangien geht dasselbe der Regel nach schon gleichzeitig mit der Reife der Zoosporen zu Grunde und persistirt nun in einzelnen Fällen; bei den Trichosporangien bleibt mindestens der ältere Theil des Mutterzellgewebes gewöhnlich stehen, während die jüngeren Generationen—ob immer?—zu Grunde gehen; aber in einzelnen Fällen wird auch hier das ganz Mutterzellgewebe resorbirt und dann erscheinen die Trichosporangia wie uniloculäre Organe."

Although conjugation between the escaped swarmspores of the multilocular sporangia was carefully looked for, no instance of it was detected. GOEBEL,† however, has already pointed out that such swarmspores conjugate during summer, when two neighbouring sporangia burst simultaneously. Probably the inertness induced by the lower temperature of the watery medium in December was enough in itself to check any such reproductive process.

Although in most cases specimens of *Ectocarpus siliculosus* which were affected with parasites did not bear true normal reproductive organs of any kind, I have, in one case, seen young multilocular sporangia and parasitic Rhizophydia on the same plant, but in no instance have I found these sporangia to be mature.

In conclusion, it would appear that the effect of the presence of Rhizophydium in Ectocarpus cells is to produce results analogous to those found in animal tissues that have become invaded by Bacterial germs of disease. That there is primarily the same stimulation, which, however, does not advance so far as to induce rapid cell divisions, as happens in the case of Bacteria, is manifested by the fact that the parasite containing cells are usually of a somewhat larger

* Pringsheim, *loc. cit.*, p. 169, 170.

† Goebel, *Bot. Zeit.*, 22nd March 1878.

absolute size than the other cells of the thallus. This stimulation is no doubt caused by the waste products evolved by the parasite as well as by the very presence of the latter inside the host cell. Moreover, in both cases, there is the same final result, namely, complete devitalisation of the organic substance, and the ultimate death of the host.

All the figs. on Plate CXLVIII. have been drawn by the aid of Abbe's camera: fig. 7, under Leitz's microscope Oc. 1, Ob. No. 10 Hartnack (water immersion); the other figures under Zeiss's microscope Oc. 3, Ob. CC.

EXPLANATION OF PLATES CXLVII., CXLVIII.

Plate CXLVII. represents a specimen of *Ectocarpus siliculosus* richly covered with the parasitic *Rhizophydium Dicksonii*. The latter occurs in various stages of development on the ultimate and penultimate ramuli of the host which bears none of the ordinary fructification.

On Plate CXLVIII. various conditions of the parasite may be observed.

Fig. 1 shows a host cell enlarged, rounded, and containing a Rhizophydium of considerable size, and bounded by a faint though distinct cell wall.

Fig. 2, *a*, represents the earliest stage of the parasite that has been observed, while the adjoining cell (fig. 2, *b*), contains a large reniform Rhizophydium, which, however, has not caused the usual bulging of the host cell wall.

Fig. 3 shows a condition in which three adjoining host cells have been attacked.

Fig. 4. Here the host cell is slightly swollen, and the parasite, instead of being perfectly round, has expanded somewhat in a lateral direction, and shows slight involutions on two opposite sides.

Fig. 5 represents a perfectly elliptical Rhizophydium lying in a somewhat swollen host cell.

Fig. 6 shows a parasite which possesses a remarkable indentation on one of its margins. The host cell is very much enlarged and rounded.

Fig. 7 is a very much enlarged representation of a parasite which has just ruptured. The broken margins of the host cell wall are well seen, as also the creases of the cell wall of the parasite.

Figs 8*a*, 8*b*, and 8*c* show the positions of the points of rupture of the cell wall of the parasite, with reference to the direction of the axis of the filaments of the host plant.

Fig. 9 shows a remarkable involution of the cell wall of the host plant, rupture having taken place at the diametrically opposite point.

Fig. 10 shows a peculiar reticulation of the spores of the parasite, which occurs just before rupture of its cell wall.

Fig. 11, *a*, represents the angulated condition in which the spores exist at and before the period of rupture. This is the result of mutual pressure caused by the continued growth. In fig. 11, *b*, a very much enlarged cell is seen, which is also obviously affected by the presence of a parasite.

In fig. 12 the angulation of the parasitic spores, the creasing of the cell wall, and the positions of rupture of the parasite, may be studied.





Fig. 1

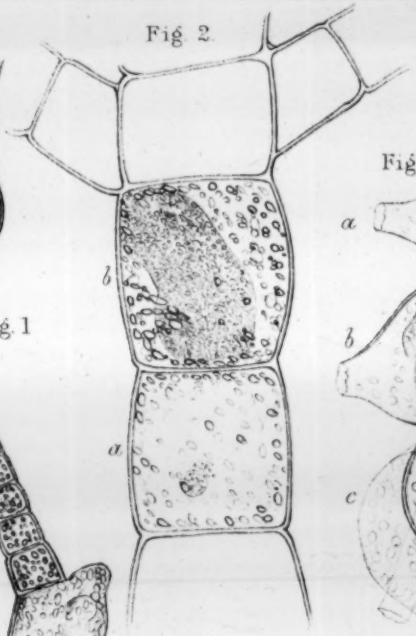


Fig. 2

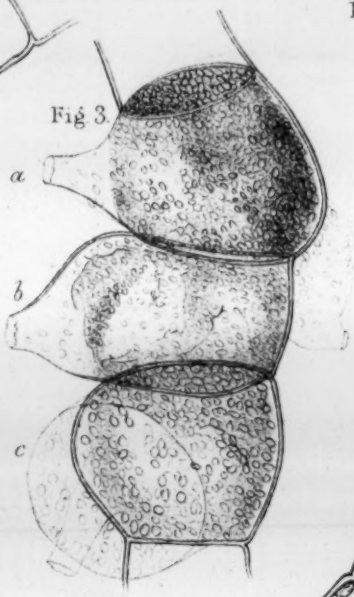


Fig. 3

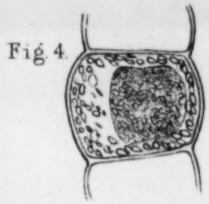


Fig. 4



Fig. 5



Fig. 6



Fig. 8 (a)



Fig. 8 (b)



Fig. 8 (c)

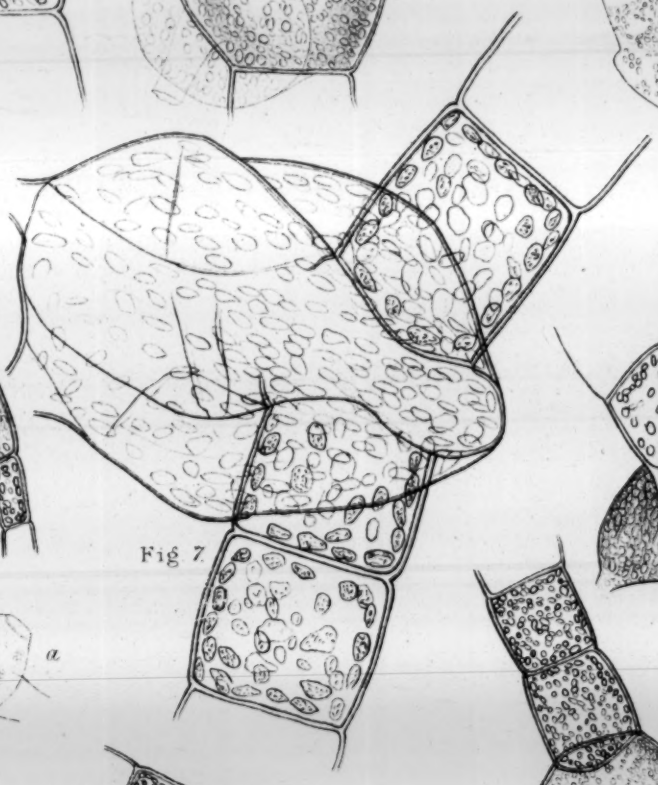


Fig. 7

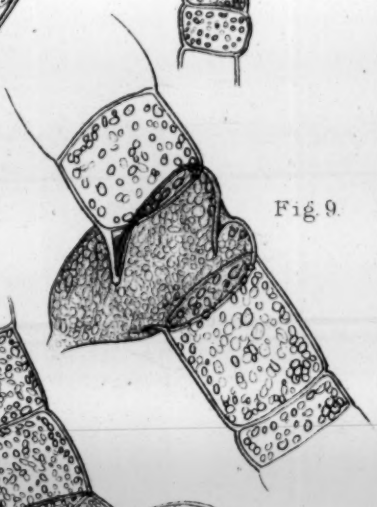


Fig. 9

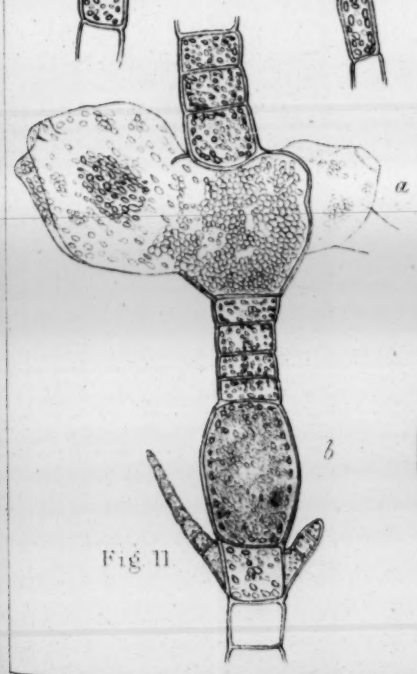


Fig. 11

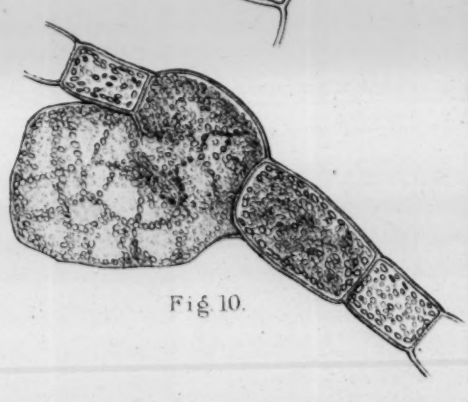


Fig. 10.

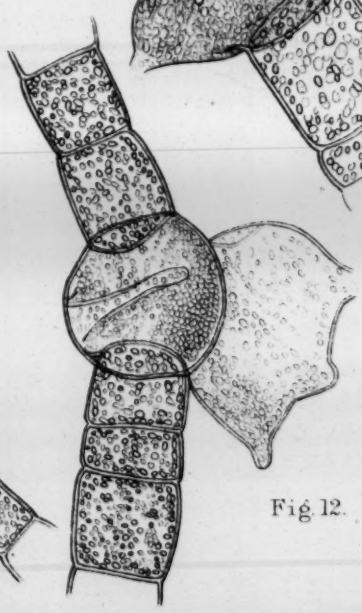


Fig. 12.

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XXXIII.—*Anatomy and Physiology of* Patella vulgata. Part I. Anatomy.

By R. J. Harvey Gibson, M.A. Communicated by Professor Herdman, D.Sc. (Plates CXLIX.–CLIII.)

(Read 5th January and 20th July 1885.)

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Introduction.

The following research was undertaken chiefly with the object of furnishing a complete memoir on the morphology and physiology of *Patella vulgata*. A number of isolated observations on various organs are recorded, but no systematic account has as yet been written, so far as the writer is aware. He has endeavoured to incorporate these observations in such a general account, having first convinced himself of their accuracy so far as lay in his power.

The paper is divided into two sections. Part I. deals solely with Anatomy and Histology; Part II. will contain an account of the Physiology of the systems described in Part I. An attempt will be made to give a description of the as yet uninvestigated development of *Patella*. These observations will doubtless afford material for certain conclusions bearing on the phylogeny of the *Patellidæ*.

All the observations described in Part I. were made on specimens obtained from Granton, the Gareloch, Loch Goil, and Firth of Clyde, fresh or preserved in spirit, or a saturated solution of picric acid.

The research was conducted in the Zoological Laboratory of University College, Liverpool; and the author is indebted to his friend Professor Herdman, D.Sc., not only for permission to make these observations in his laboratory, but also for constant advice during the prosecution of the work. His best thanks are also due to Dr Murie, F.L.S., for the great assistance rendered by him in the bibliography of the subject.

Historical Account.

As indicated above, the investigations into the minute anatomy of the limpet are not numerous, and with few exceptions exceedingly fragmentary and contradictory. Dall, in a recent paper, afterwards to be referred to,

expresses a hope that the anatomy and development of this form may be taken up by some one; and although it is to be regretted that the task had not fallen into more competent hands than the present writer's, yet he hopes that he has, in the following research, done something towards dispelling the prevailing uncertainty in regard to many questions, which have too long demanded investigation. The desideratum at present in the natural history, more especially of the Mollusca, is a series of complete accounts of all the more common types; and it seems to the author that much more might be made with regard to interesting problems of Phylogeny, if, instead of elaborating a number of small detached papers on special points, some naturalists were, for a few years at least, to devote themselves to the working out of complete monographs of the most important forms belonging to each group.

A considerable amount of work has been done in the way of naming and identifying the numerous species of the *Patellidæ;* although, owing to their identification being based on unimportant external features, *e.g.*, the form and colour of the shell and exposed parts, many forms have received several synonyms, and have consequently been described several times.

In this summary of research, the author desires rather to indicate the leading papers on which our knowledge of *Patella* is based, than to give any detailed account of these papers themselves, which he prefers to postpone until the different organs with which they deal come to be discussed.

The limpet is mentioned first, of course, by the all-observant Aristotle, who gives a brief account of some of its more obvious characters and habits,—referring especially to its moving from place to place and returning after each forage to its old roosting place. General descriptions have been given by Linnæus, Born, Adanson, and various other naturalists of the last century; and we are generally able to identify the species described by them with those now inhabiting our coasts. Similar accounts are given by later conchologists, more especially by Reeve, Hanley, Gwyn Jeffreys, Gray, and Woodward.

The first attempt at giving a complete account of the anatomy of *Patella* is that of Cuvier in his *Memoires*, where the species is described with tolerable fulness. Gray, and later Dall, have described and figured the radula, the mechanism of which has been lately fully investigated by Geddes. The renal organs have come in for a good deal of attention from Lankester, Dall, and Cunningham, and are perhaps the most thoroughly investigated portions of the whole animal. The respiratory organs have not been so fortunate, having been examined, in allied forms only, by Williams (whose paper the writer has not been able to see). Some remarks on the respiratory organs by Blainville and Adanson are mainly contradictory of each other. The nervous system has been investigated by Brandt and by Spengel; and their admirable work leaves little to be done in that system, save to make a few remarks on histology. Spengel

also gives an account of the olfactory organ; and FRAISSE describes and figures the eye of an allied species. LACAZE DUTHIERS has investigated the auditory organs. With regard to the reproductive system there is great uncertainty, the existence of oviducts and of vasa differentia being asserted and denied repeatedly. CUVIER asserts the presence of an oviduct; DALL in one research thinks that he has seen it, and in another he denies that it exists. LANKESTER describes two so-called "capitopedal orifices," which he took to be the openings of oviducts, but which he now believes are the rudiments of true gills; DALL denies their existence altogether. GRAY mentions the presence of reproductive glands, but gives no details.

Many authors have made observations on the habits of the limpet, and some few notes on its development have been published by FISCHER; these researches, however, do not fall to be discussed in this part, since they are rather physiological than anatomical in their nature.

MORPHOLOGY.

1. *External Form.*—In size, *Patella vulgata* varies from $\frac{1}{2}$ inch to $2\frac{1}{2}$ inches in maximum antero-posterior diameter. The maximum transverse diameter is about $\frac{3}{4}$ to $\frac{7}{8}$ of the maximum antero-posterior diameter.

In a typical moderately large specimen, say 2 inches long, the short diameter is about $1\frac{3}{4}$ inch, the height of the dome about $\frac{9}{10}$ inch; but in no case are the relations of the measurements perfectly constant.

Before removal of the shell, such a specimen is seen to be dome-shaped, the apex being rounded. The marginal outline of the shell is oval, the narrow end corresponding to the head end of the animal; the apex of the dome is nearer the anterior end. The rim of the shell is sharp and irregularly notched; it is also bevelled, the bevelled side being inner. Two series of markings are visible, one series running from the apex to the edge of the shell, *i.e.*, radial, the other concentric with the edge. Internally, bands of colour of varying tint replace the radiating lines. The radial lines, externally, are usually tuberculate.

The body is surrounded by the mantle skirt, which in specimens preserved in spirit extends beyond the ventral surface of the foot, owing to contraction of the muscle of that organ, but which naturally reaches a point midway down the side of the body. The mantle skirt is notched or wrinkled and pigmented. It usually retreats somewhat from the shell, its extreme edge forming a thickened rim.

From the inner surface of the skirt, throughout its entire circumference, there depends a series of lamellæ, the functional gills. These occupy a grove, or valley formed by the mantle on one side, and the concave side of the muscular

foot and of the circular muscle which attaches the foot to the shell on the other. This band of muscle is discontinued at the anterior end for a space equal to about $\frac{1}{6}$th of the circumference; which space is occupied by the head. The mantle and gill processes are, however, continued round the anterior end, and depend in front of the head.

The head is distinct, and a slight narrowing indicates a rudimentary neck region. The oral disc (Pl. CXLIX. fig. 1), in the centre of which is the oral aperture, is corrugated and kidney-shaped in outline, the hilus being ventral. On either side of the head there is situated a pointed more or less pigmented tentacle (the "nuchal" tentacle), usually from $\frac{1}{4}$ to $\frac{1}{3}$ of an inch long in its contracted condition, but, when extended, in large limpets as much as $\frac{3}{4}$ to an inch in length. On either side of the neck there may be seen an oval yellowish body, the rudimentary gills or ctenidia. They are usually about twice their own length from the circular muscle. They vary in length according to the size of the animal, from $\frac{1}{15}$ to $\frac{1}{20}$ of an inch (Pl. CXLIX. fig. 3).* Over the right shoulder may be seen the anal papilla, and the right and left renal papillæ, one on either side of it. Ventrally the muscular foot is seen widening as it passes downward, and having a thin rim as its ventral edge.

On removal of the shell, the visceral dome is exposed, and found to be covered by a deeply pigmented membrane. The colours are deep indigo, streaked with dull yellow. The yellow tinge being due mainly to the subjacent viscera shining through the visceral integument. The superficial dark pigment layer is easily scraped off (Pl. CXLIX. fig. 2).

The muscle connecting the foot and the shell is now visible, on surface view, as a ring, incomplete in front, of uniform width, save at its anterior extremities, which are rather wider and rounded off. The superficial pigment is most abundant near the muscle band.

The eyes may be made out as minute black specks, one on either nuchal tentacle, on a slight prominence on their outer aspect, near the base.

General Arrangement of the Viscera.—The general arrangement of the viscera may be made out on removal of the shell, and after the superficial pigment layer of the visceral integument has been scraped off. If the integument itself be removed, the relation of the viscera may be still better defined (Pl. CXLIX. fig. 3). The integument must be removed with care, as it is intimately related in some parts to the subjacent tissues. The free edge of the mantle over the cephalic region being also removed, the visceral mass is seen to be bounded anteriorly by a ridge, from which project forwards on the right hand side the anal and renal papillæ. From the anal papilla, the rectum passes backwards transversely for a certain distance, and then passes circularly round

* In the figure they are represented as too near the middle line and too near the base of the tentacle.

the visceral mass. Posteriorly to the rectum, and supporting it, lies the genital organ (male or female), which at certain seasons is very large, and forms a crescentic mass, on surface view, enclosing and supporting the other organs. It is wedge-shaped, and extends along the floor of the visceral cavity, its thick edge forming the crescent above mentioned.

Between the rectum and the genital gland, and spreading round the former and sending projections over the latter so as to enclose it, is the posterior portion of the right nephridium. It may be traced as a dark brown mass passing up the right side. It is very variable in form, sometimes scarcely apparent on surface view, at other times ramifying extensively over the dorsal surface. It varies in colour from a brown yellow to a deep burnt umber. On the extreme right may occasionally be seen a portion of the lingual ribbon in its sheath. The right nephridium usually extends for $\frac{2}{3}$ of the circumference of the visceral mass.

The centre of the visceral dome is occupied by the liver, a granular villous mass of yellowish-green colour. It is enclosed by a coil of intestine, which springs from and ends at the right side, and which separates it from the right nephridium. Between the anterior bend of this coil and the rectum lies a branch of the right nephridium.

Anterior to the rectum, and between it and the anterior boundary ridge, there is a quadrilateral region, which is divided into two by a fibrous septum. That part, usually more or less triangular in outline, lying nearer to the anal end of the intestine, is entirely occupied by a light brown body, the left nephridium. The rest of the space is white and fibrous in appearance, and forms the dorsal wall of the pericardium. The visceral integument is free from the viscera, save where it lies upon the nephridia and pericardium, with both of which it is intimately connected.

Born and Reeve, among the older naturalists, give the fullest accounts of the external features, the former in his *Testacea Mus. Cæs. Vind.*, the latter in his *Conchologica Iconica*. Cuvier gives a short description of the soft parts visible without dissection (*Mémoires pour servier a l'historie et l'anatomie des Mollusques*). Gwyn Jeffreys (*British Conchology*) gives the most complete recent account, but errs in saying that the shell is opaque. None of the shells examined by the writer were altogether opaque; the majority were translucent, though some were less so at the apex than elsewhere.

2. *Alimentary System.*—The alimentary system is very complicated, and has not hitherto been investigated in any detail. The following account does not profess to be perfectly complete, either macroscopically or microscopically; and the difficulties in the way of a thorough and accurate examination of all the parts are such that it cannot profess to be final either. Many points yet require a more detailed investigation, which the writer means to undertake in

connection with the physiological section of this research. With that intention he has omitted certain histological details, more especially into the minute structure of the crop, the openings of the bile ducts, &c., with regard to which it may be possible to obtain some information when the physiology of these parts comes to be investigated.

Considering the alimentary canal first of all macroscopically. The buccal cavity is entered by an oval or kidney-shaped opening on the oval disc. Immediately within the circular puckered outer lip which guards the opening is a shallow cavity, which is closed posteriorly by a pair of inner lips. These inner lips are two stout flaps of muscle which rise vertically from the floor of the buccal cavity, and project almost to the roof. They leave between them a narrow vertical slit, through which the odontophore may be seen (Pl. CLII. fig. 54, *a*). Within these lips a large irregular chamber is found, which may be termed the pharyngeal chamber. Its form may best be understood by following the reflections and foldings of the pharyngeal mucous membrane (Pl. CLIII. fig. 62). Ventrally the mucous membrane, starting from the inner aspect of the inner lips, runs along the floor of the chamber for a short distance until it has reached the middle of the odontophore. There it bends anteriorly, and is reflected up over the anterior part of the odontophore. Laterally the mucous membrane follows a similar course, being there reflected over the sides of the odontophore. The mucous membrane then passes beneath the radula, forming the subradular membrane. At a short distance from the centre of the dorsal surface of the odontophore the membrane unites above the radula,—forms in this way a bag for its reception. Indeed, the radula is an epidermic modification of the pharyngeal mucous membrane. The radula lies folded in this bag, from the wall of which it is developed. The bag is suspended among the viscera, usually to the left side, sometimes, however, on the right, more rarely still in a spiral coil on the floor of the visceral cavity.

Returning to the pharyngeal mucous membrane, dorsally it springs from the palate, and when it has become free from the body or neckwall, and uniting with the lateral portions of itself, passes backwards over the dorsal surface of the odontophore. After passing the origin of the radular sheath, it unites with the ventral portion, and becomes the pharynx proper.

On the palate and on the floor of the pharyngeal chamber, there are two structures which require mention. These are two plates which protect the subjacent tissues from injury from the teeth of the radula. The palatal plate (Pl. CL. fig. 17, and Pl. CLIII. figs. 63 and 64) is sunk in the tissue of the palate, and like the radula and the ventral plate, is a development of the pharyngeal mucous membrane. Looked at from below, it presents a central triangular area, which is of a brown colour, and from which posteriorly (apex) project two large almost colourless flaps; from the (base) anterior end also

project two smaller wings. These wings are sunk in the tissue, the triangular central piece being that against which the radula works. The anterior smaller wings are seen to be flaps of a collar which is formed by the turning back of the plate. In other words, the anterior flaps are on a higher plane than the posterior flaps. The palate is slightly depressed where the anterior margin appears; and the plate itself is curved, the concavity being ventral, and being the groove in which the radula slides. Since the radula passes over the anterior end of the odontophore, the teeth are therefore brought into contact with the floor of the buccal cavity. There accordingly is found another plate (Pl. CLII. figs. 55, 56), which has not hitherto attracted the attention of describers of the hard parts of the limpet. It is not so large nor so distinct as the other, but that it affords protection to the tissues at that point, is shown by the fact that the surface of the plate is furrowed by the radular teeth. The entire plate (as described below) is simply a thickened cuticle. The pharynx, behind the palatal plate, becomes distinct above. It has very thin and delicate walls. It may be seen to be 3-chambered, or rather to have two very evident folds running down one on either side (Pl. CLIII. figs. 61, 62). The wall of either lateral division has a very manifest thickening of a yellowish colour, where the salivary ducts enter. The roof also of the pharynx has posteriorly a large number of mucous glands in it, which give it a white appearance, as contrasted with the more transparent anterior portion.

The buccal mass now falls to be described. And, first of all, having theoretically stripped off the pharyngeal mucous membrane, the radula must be noticed as distinct from the odontophore and its muscles. The radula is a narrow belt usually about (in a moderately-sized limpet) $\frac{1}{16}$th of an inch broad, and about twice the length of the animal in length. Anteriorly it widens out into a flat plate, in the centre of which is the radula proper. The plate and radula is merely a modified cuticle. The plate is bent over the front end of the buccal mass. It is fastened to the mass beneath, whilst, superficially and posteriorly, it sinks beneath the level of the muscles of the buccal mass, and runs into its sheath as already described. Towards the posterior end the teeth gradually disappear, and ultimately it ends in a soft hammer-shaped knob. Its minute structure will be described under the histology of the alimentary system. The odontophore itself is composed of muscles and cartilages. The buccal mass (Pl. CLIII. fig. 65), deprived of its covering and radula, is ovoid, and divided almost into two hemispheres by a furrow, which runs vertically from before backward. Anteriorly the furrow widens and becomes shallow, and has a prominence in its centre, over which the radula was bent. Either hemisphere is composed, therefore, superficially of a mass of muscle whose fibres run outwards and from before backwards, and are the muscles of the radular membrane. Beneath these muscles lie the cartilages. The cartilages are six in

number—two anterior, two posterior, and two lateral. The anterior cartilages are the largest; they are pointed and slightly curved upwards in front, and are arranged like the legs of the letter V, with the apex pointing towards the mouth (Pl. CLIII. fig. 66). At the bases of the legs lie the posterior cartilages, and closely attached to them. The posterior cartilages are square blocks with corners rounded off. The lateral cartilages lie alongside the anterior cartilages, and towards their anterior ends. They are triangular in shape, having the base of the triangle anterior. These various cartilages are bound to one another (*a*) by connnective tissue, and (*b*) by muscles. (*a*) Distinct bands of connective tissue bind the posterior cartilages to the anterior, and also the lateral to the anterior. (*b*) There are also a number of muscles which connect the various cartilages to each other; a band uniting the anterior and lateral cartilages on either side, dorsally; two bands or sheets uniting the two anterior cartilages, ventrally; the upper of these being the broader and larger, and being separated from the under narrower band by two bands of muscle passing from the infra-radular membrane to the base of the posterior cartilage on either side; and, lastly, a band uniting the anterior and lateral cartilages on either side, ventrally. All these muscles may be termed intrinsic. There are, however, in addition several extrinsic muscles connecting the buccal mass with the neck wall. Firstly, two broad plates attached posteriorly, one on either side to the posterior cartilage, anteriorly to the floor of the neck cavity. These may be termed the ventral protractor fibres (Pl. CL. fig. 17, *v.pr.*). Also attached to the posterior cartilage on either side is a lateral protractor, which is attached anteriorly to the roof of the neck cavity. Finally, attached laterally to the anterior cartilage, on either side, is a vertical band of muscle, attached at its upper end to the roof of the neck cavity. Many delicate muscular fibres also pass from the pharynx to the walls of the neck cavity.

Returning now to the pharynx, it is found, as already stated, to be more or less divided externally by two longitudinal furrows into three parts, a central and two lateral. These several parts are in complete communication with each other, the division being rather apparent than real. Anteriorly the wall of the pharynx is thickened by the development of two oval yellowish-brown masses, one on either of the lateral divisions. Into these masses the four very evident salivary ducts open, two into either mass (Pl. CLIII. fig. 61). The ducts are long isolated, slightly twisted, yellowish-brown tubes which run from thence backwards, the two inner lying in the furrows of the pharynx, but easily detachable therefrom, the two outer running alongside the odontophore. The two inner enter the salivary glands about the middle; the two outer are attached to the glands at their extreme edges (Pl. CLIII. fig. 61). The glands themselves vary somewhat in size and colour. They are usually large orange-coloured masses closely united together, lying over the shoulders, beneath the pericardium on one

side, and the renal and anal papillæ on the other. The pharynx widens considerably after becoming free from the buccal mass, and two deep pouches, the continuations of the lateral divisions of the pharynx, lie on either side of the neck in front of the salivary glands. The so-called "crop" (the name is very inappropriate) is a long thick-walled sac continuous on the one side with the pharynx, on the other with the œsophagus. The folds in the pharynx are continued to the crop, which has other transverse folds of its own. The interior has been justly likened to the maniplies of a sheep's stomach. Round the "crop" and the true stomach, which lies above it, is the liver, an irregular yellowish mass which fills up all the intervening space between the "crop," stomach, and coils of intestine soon to be mentioned. It is a compound tubular gland, supported by a framework of connective tissue. The biliary secretions appear to be poured into the crop at many points; more accurate information must be obtained, however, with reference to that point. The œsophagus is of small and uniform diameter; it makes one short coil on the floor of the visceral cavity and then widens into a long stomach, which is doubled on itself, and lies across the centre of the body (when not displaced by the greater size than usual of the genital gland), the blunt or folded end lying behind the pericardium, but usually separated from that by one or two folds of intestine. The two halves of the stomach are closely applied. From the pyloric end of the stomach the intestine springs, and maintains throughout its entire length a constant diameter, viz., about equal to that of the œsophagus. The intestine immediately after leaving the stomach bends sharply back and runs beneath the folded end of the stomach round to the head, passes in front of the cardiac portion of the stomach, over the buccal mass, and, on reaching the extreme edge of the visceral sac on the left side, bends sharply upwards, and coils over a subsequent loop of intestine. It then forms a superficial loop on the dorsal surface, over the top of the stomach, passes again back to the point at which it bends upwards, and there bends downwards. The ascending and descending portions touch one another at that point. The intestine then travels along the floor of the visceral sac, and, after making a complete circuit of the sac, passes forward, and, curving backward once more, forms that portion of the intestine which is looped over by the ascending and descending parts above mentioned. It makes one more complete circuit of the visceral sac, and then ends at the anal papilla on the right shoulder.

The columnar epithelium of the exterior epiderm is continued into the interior of the alimentary canal. The pharynx is lined with columnar epithelium resting on a layer of connective tissue and muscle. Over the roof of the pharynx, both in the central and in the lateral divisions, there are many convoluted compound tubular mucous glands. The secretion of these glands, which is poured into the buccal cavity, is thick and viscous, and contains many

cast-off epithelial cells. At the palatal plate, and also at the ventral plate, the epithelium becomes many layers deep (elsewhere it is in a single layer, save in the glands), and the superficial cells secrete a very thick cuticle which becomes modified into the distinct and separable palatal plate in the one case, but in the other remains attached to the cells (Pl. CLII. fig. 56). Beneath the edges of the ventral plate the connective tissue forms two soft pads.

The radula, which lies in a long sac formed by an out-pushing of the pharynx, from the wall of which it is developed, is a ribbon, expanded at the anterior end into a flat plate, which is wrapped round the anterior cartilages, and is continuous with the pharyngeal mucous membrane, viz., with that reflection of it which covers the under surface of the buccal mass. Posteriorly the ribbon is bent on itself in its sac and ends in a soft clubbed end. The teeth are not developed in the latter part of the ribbon, though their general position is mapped out on the membrane. The various ridges are then strengthened and developed by deposition of particles of chitinous matter with which the sac is plentifully supplied. When completely formed (Pl. CLII. fig. 60) the radula is seen to be composed of a tough chitinous band, from which spring a number of teeth. The teeth are arranged in curved rows, the concavity of the row being anterior. The radula tends to tear in that way. Each row consists of ten teeth. The four central teeth (4, 5, 5, 4) are similar in shape, although the middle two are slightly smaller than the exterior two. Each is composed of a yellowish root and neck, succeeded by a brown band or collar, and terminated by a black crown, which is in shape like a bird's claw, the claw having its convexity directed towards the mouth. Next to the four central teeth, and placed a little in advance of them, is, on either side, a tooth slightly larger than any of the central teeth, but similar to them in structure, save that it has three claws instead of one (3.3). Most external of all, there is a pair of teeth on either side which are flat, faintly yellow in colour, without claws; the ends are, however, slightly curved upwards and backwards. These teeth are also slightly in advance of the last mentioned, and the outer of the two is slightly beneath and in advance of the inner. The form and relationships of the teeth will be much better understood by reference to the figure (Pl. CLII. fig. 60).

The cartilages of the odontophore are composed of the usual elements. The cells are large, and the matrix (cell walls) small in amount, so that the cartilage is spongy in texture. The cells are smaller as they approach the perichondrium. The muscle fibres of the odontophore are nucleated, and are similar to those fibres found in the heart (*q.v.*).

The salivary glands are compound tubular glands. The walls of the tubules are composed of cubical epithelium with yellow granules in the cells. The outlines of the cells are difficult to make out. The salivary ducts likewise are

lined by cubical epithelium. Both tubules and ducts are supported by a basement layer of connective tissue. The ducts enter the pharynx towards its anterior end, and where they do so there is a large mucous gland, the cells of which, however, are largely supplied with the yellow granules found in the salivary glands. The pharynx is a very complicated structure, and its fuller investigation is left to the physiological part of this research. In the anterior part there are two distinct folds from the dorsal wall; the lateral chambers are continued into a pouch over either shoulder. These folds, along with others on the ventral wall, are continued into the crop. The entire pharynx is lined with columnar epithelium.

The crop is thick-walled, but in reality the thickness is due to the presence of an enormous number of long compound tubular follicles, much resembling those found in the large intestine of a mammal. There are two very distinct longitudinal folds running from one end of the crop to the other on the ventral wall, and also one pretty definite fold on the dorsal surface. Each of these folds has secondary longitudinal folds on itself. Further, the wall generally is thrown into transverse folds, which are arranged like a series of leaflets across the intervening spaces. On these folds are developed the follicles above-mentioned. The follicles are lined by elongated cubical or columnar cells, two or three layers deep. The superficial layer is composed of pear-shaped cells, which are filled with granular protoplasm. The larger cells contain rounded granular masses of a highly refractile nature. These masses are often placed in a vacuole, and are apparently shed into the lumen of the follicle. The cells spring from a basement membrane of connective tissue cells, and there is a lymph space between every two follicles. These spaces communicate with the spaces in the connective tissue surrounding the glandular stomach, and consequently with the circulatory system.

The liver, as already stated, is a compound saccular gland, irregular in form, and filling up generally the spaces between the glandular stomach, the true stomach, and the various coils of intestine. It consists of a framework of connective tissue, covered by secreting epithelium. The epithelium is one layer deep, and is extremely difficult to make out, so full is the whole tissue of biliary secretion. When the débris is washed away, usually the epithelium is also removed. When found, it is seen to be composed of delicate columnar or cubical cells, without evident cell wall, and filled with the minute droplets or granules of which the biliary secretion is composed. The cells are not unlike goblet cells in form. There are usually to be seen some minute cells between the bases of these larger cells, which probably replace the larger cells when destroyed. The bile is apparently poured into the glandular stomach by a number of ducts. A fortunate section may show the opening of one of these ducts (Pl. CLIII. fig. 71). The ducts open between the bases of the two

follicles, and is lined by nucleated squames. Apparently the liver tubules open into a single lobular duct, which passes between the irregular lobes into which the liver is divided. There does not appear to be a common bile duct.

The stomach proper is a large sac, with a very thin non-glandular wall. The epithelium is often ridged, but the arrangement of the ridges is not constant. The epithelium is very beautiful columnar, ciliated two or three layers deep. The wall is composed of the usual muscle (non-striated) and connective tissue. There are abundant blood spaces in the gastric wall.

The entire alimentary canal is lined throughout by columnar ciliated epithelium one layer deep, but with young cells inserted between the bases of the superficial large cells. The alimentary canal has, in various parts, the power of secreting in its interior a whitish rod. The nature of that structure will be discussed in the physiological section, with the subject of secretion generally.

The rectum is often ridged and papillose, in a manner similar to the rectal papilla. The muscle is circularly arranged, and the fæces escape in masses more or less like strings of beads. The cilia of the alimentary canal must be eminently useful in preventing obstruction in the course of a canal of such length.

The rectal papilla, which projects a variable distance from the anterior edge of the visceral mass on the right shoulder, is composed of a thick layer of circularly-arranged muscle fibres, thrown internally into ridges and papillæ, the whole interior being covered by columnar ciliated epithelium. The cilia are very long, and the cells very distinct and perfect. They are arranged in a single layer. The papillæ are in most cases compound, and they, assisted by the cilia, no doubt prevent the entrance of infusoria and other small creatures into the rectum.

The alimentary canal and its connected glands have received less attention than any other part of the animal. With the exception of Cuvier (*loc. cit.*) no one has done anything towards unravelling the apparently endless coils in which the intestine lies. The dissection is attended with great difficulty, not only on account of the extreme tenderness of the intestinal walls, but also on account of the intricate way in which the coils are intertwined, and the intimate connection subsisting between them and the liver, right kidney, and connective tissue supporting these organs. Out of over a score of limpets, which the author dissected with a view to the untwining of the alimentary canal, he was successful in only one case; and it measured over 14 inches in length, the antero-posterior diameter of the animal itself being $2\frac{1}{4}$ inches. Cuvier's figure errs in showing far fewer coils than there really are; he excuses himself by saying that the directions in which it twists are "assez inutiles à décrire!" The stomach also is inaccurately drawn. The buccal mass, its cartilages and

muscles, are described and figured by GEDDES (*Trans. Zool. Soc.*, x. 485). LANKESTER (*Ann. and Mag. Nat. Hist.*, 1867) confirms CUVIER'S discovery of a crop of salivary glands, and says they (the salivary glands) open into the buccal cavity by four ducts. DALL (*Amer. Jour. Conch.*, 1871) figures and describes the radula; as does also GRAY (*Sys. Distrib. of Mollusca in Brit. Mus.*).

3. *Circulatory System.*—The circulatory system consists of a branchial vein and veinlets, a heart, and two efferent vessels.

The branchial vein is easily seen in fresh specimen as a large clear belt beneath (ventral) the circle of gill lamellæ, when examined in section. It cannot be distinguished from a large lacuna. No special lining of epithelium is visible; its walls are composed of connective tissue. Crossing it at regular intervals can be seen clear veinlets, which however do not open into the branchial vein. These veinlets spring from the mantle skirt beyond the branchial vein,—*i.e.*, nearer its edge,—and open into lacunæ at the origin of the gill lamellæ. From the gills again arise veinlets (Pl. CLI. fig. 38, *e*), which open into the branchial vein (Pl. CL. fig. 28). The branchial vein surrounds the entire mantle skirt, and the ends unite to form one vessel, which passes over the left shoulder to enter the pericardium at its extreme left corner. The vessel, as it passes round the pillar-like termination of the circular muscle, becomes surrounded by fibres of muscular tissue, which are continuous with the fibres of the auricle into which the vessel immediately opens (Pl. CLI. figs. 41 and 43).

The pericardium, which is continuous with the visceral integument, but thicker, is composed of very tough connective tissue, to which muscle fibres are attached on its inner aspect for the support of the heart. It is lined internally with squamous epithelium, often scarcely visible owing to its thinness.

The heart consists of two chambers, an auricle and a ventricle. The auricle is large, and very thin-walled. It is attached to the pericardium at some points, especially in front. The attachment at that point is extensive, and the writer has not been able to convince himself that no communication exists between the auricle and the very vascular cephalic portion of the mantle. He has not been able to force any injection into the auricle from the lacunæ, nor has any injection passed into the lacunæ from the heart, so far as he can make out. It is possible, however, that further injection experiments, which he purposes trying, may lead to different results. [These experiments the author has since made, with the result that he feels convinced that the mantle in the head region acts as an accessory respiratory organ, and that the blood from that area enters the auricle by openings in the "attachment" referred to.] The auricle is very distendible. It opens into the ventricle, which lies beneath it, by a slit which is guarded by muscle fibres rather curiously placed. The fibres are continuous with others which form a network inside the

ventricle, rendering it more or less of a sponge. From the arrangement of the muscle fibres round the auriculo-ventricular opening, contraction of the ventricle must bring about contraction of these muscle fibres, and cause occlusion of the opening, thus preventing regurgitation (Pl. CLI. fig. 44).

The ventricle is practically a sponge of muscle fibres. It is oval, and more or less pointed in shape at the ends, where it opens into two aortæ. The long axis of the ventricle runs transversely,—that is, from right to left. The left aorta, or efferent vessel, passes into and supplies the circular muscle. The right, after passing out of the pericardium at the posterior right-hand corner, breaks up and opens into a very perfect system of lacunæ. Although the writer has made many injections with carmine gelatine in fresh specimens, he has never been able to trace the vessels beyond a very short distance. The right efferent vessel runs beneath the rectum.

The wall of the auricle is composed of diagonally arranged belts of muscle which are held together by single nucleated muscle and connective tissue cells. The fibres seem embedded or covered by a connecting membrane with small nuclei scattered in it, which may represent squamous epithelium (Pl. CLI. fig. 39). The ventricle has a similar structure, but the muscle fibres cross and recross in the interior of the ventricle.

The muscle fibre of both auricle and ventricle is composed—the auricle partly, the ventricle wholly—of a species of striped fibre common enough in invertebrate hearts. The transverse striation is not very distinct, and it gives the individual fibres rather a granular appearance. Bundles of fibres are enclosed or wrapped round by nucleated connective tissue cells (Pl. CLI. figs. 39 and 45.

The blood corpuscles (Pl. CLI. fig. 42) are colourless and amœboid. They appear something like spiny balls; though here and there flatter, more irregular corpuscles are visible. Each contains one or more nuclei, and is composed of granular protoplasm. When a coagulum is formed, the pseudopodial processes anastomose, and the clot under the microscope resembles a plasmodium of *Monobia*.

With the exception of Cuvier's (*loc. cit.*) brief remarks on, and rather meagre drawing of, the heart, and Williams' reference to the structure of the blood corpuscles (quoted by Dall in his paper on "Limpets" in the *Amer. Jour. of Conchology*, 1871), the writer has been unable to find any observation of importance on the circulatory system. Lankester (art. "Mollusca," *Ency. Brit.*, 9th ed.) makes a brief reference to it, but does not enter into any detail.

4. *Purificatory System.*—(*a*) *Respiratory System.*—The functional gills are in the form of lamellæ, arranged round the inside of the skirt of the mantle. They are morphologically processes of the mantle. They are attached to the mantle in an oblique manner, so that a transverse (*i.e.*, vertical) section may cut through

two or more lamellæ. Under the low power they appear as flattened pockets more or less triangular in form, with a base attached to the mantle, and with the apices projecting into the valley between the mantle and the foot (Pl. CLI. fig. 38).

The structure of the mantle and of the gills is so similar, and since, as shall be afterwards shown, the mantle is also respiratory in function, it may be best to describe them together.

Under the low power (Pl. CL. fig. 24) a vertical section shows the mantle to be attached to the circular muscle just where it springs from the shell, and to extend as a plate thickened in its outer third, and having certain processes springing from its ventral surface, which are vertical sections of gill lamellæ. The entire surface of the mantle is covered by epithelium, which is in many places greatly wrinkled. The mass or body of the mantle consists of connective tissue and muscle, with large and small lacunar spaces. The lamellæ are also hollow, and their opposite walls are connected by transverse bands of tissue.

When the epithelium is examined under a high power, it is found to be columnar, but presenting variations in structure at different parts.

The epithelium over the dorsal surface of the mantle is low columnar, with large nuclei. Towards the attachment of the circular muscle it becomes squamous, which again becomes continuous with the dense epithelium covering the surface of the circular muscle. Outwards, the cells become longer and more tapering. They are arranged in fan-shaped masses owing to the corrugation of the surface. The tapering ends (Pl. CL. fig. 25) are individually attached to the fine ends of transverse muscular fibres, while the free ends, which are more granular than the bodies of the cells, are covered with a continuous homogeneous cuticle. Just beneath the epithelium, and separating the fine tapering extremities of the cells from one another, lies a layer of muscle which runs in a circular manner round the mantle edge, *i.e.*, in vertical section the ends of these fibres are cut across. These fibres are extremely close to the epithelium, and are not separated from it by any basement membrane or connective tissue. Beneath this layer, and closely applied to it, is another layer, which is arranged vertically, *i.e.*, parallel with the long axis of the section, in which they are seen as strands. The transverse fibres run between these fibres, crossing them at right angles, to be attached to the tapering ends of the epithelial cells. Beneath that layer there is a quantity of connective tissue of loose texture, which is succeeded by another but much thicker layer of vertical muscle fibres, which is prolonged downwards to the very edge of the mantle skirt.

At the edge of the mantle the epithelium becomes low and cubical, and is frequently pigmented, the pigment being deposited chiefly as a band in the centre of the cells. There are frequent indentations on the dorsal surface of the edge of the mantle, the cells lining which are pigmented.

The under surface of the mantle differs in many respects from the upper surface, and resembles the structure of the gills so markedly that no doubt it is to be looked upon as functionally a respiratory organ, just as the gill lamellæ are to be considered as morphologically processes of the mantle. The epithelium covering the under surface of the mantle and the lamellæ is also columnar; at the tip it is regular and low; over the thicker part of the mantle the cells are very small and crushed, and the columnar structure is not always evident. Their outlines on surface view are ragged, and their free ends are embedded in a homogeneous membrane. Their inner ends are also ragged, the processes being sunk in the subepithelial connective tissue (Pl. CL. fig. 26).

Where the mantle again thins, and where the gills rise, the cells become regular columnar, as on the dorsal surface, and spring from a muscular layer similar to but thicker than the most superficial layer mentioned, as underlying the epithelium of the dorsal surface. The fibres are, however, frequently oblique. Above the origin of the gill lamellæ the epithelium is also columnar, and is covered by a very distinct cuticle. The muscle in this part of the mantle is arranged in a thin radial layer separated by connective tissue from the epithelium (Pl. CL. fig. 27).

The body of the mantle in its upper half is divided by transverse muscular bands into a series of quadrilateral compartments, which are lacunar blood spaces.

The thicker ventral or outer part of the mantle is composed in the main of connective tissue and muscle with scattered nerves, forming a dense network in which, however, there are lacunæ—one large one, which is the branchial vein, and several of smaller size. The whole mantle is well supplied with nerves. There are usually five or six branches, which run at uniform distances round the mantle skirt. Each is enclosed in a connective tissue sheath, and each divides up into fibres and fibrillæ, which are distributed to the muscular fibres.

Occasionally a specimen is found in which the branchial vein is enormously swollen. In such cases, the tissue of which the mantle is composed can be studied to much better advantage (Pl. CL. fig. 28). The connective tissue corpuscles are specially well developed (Pl. CL. fig. 29).

The free part of the mantle skirt over the head is similar in structure to that just described. The membranous portion has a structure like that of the visceral integument. It is composed of three layers—a superficial pigmented layer composed of cubical cells, a middle layer of connective tissue and a few muscle fibres, and a deep layer of cubical cells similar to those of the visceral integument (*q.v.*). The middle layer contains many lacunar blood spaces (Pl. CL. fig. 20).

Each gill lamella is composed of two flattened plates of connective tissue, with a few muscular fibres connected by transverse bands of connective tissue (Pl. CL. fig. 30). A single layer of columnar epithelium covers over each

side of the lamella. These cells have large nuclei, and a comparatively thick cuticle. The cells are relatively far apart, the spaces between the cells being filled probably with intercellular substance, possibly with sea water. The protoplasm of the cells is clearer, but with larger granules in the superficial than in the basal portion. The nucleus lies in the basal portion. Towards the free extremity of the lamella the cells are more flattened and more vacuolated, and the cuticle is not so distinct. All parts of the lamella and the ventral face of the mantle not occupied by the muscle and connective tissue framework above indicated are filled by a network of delicate fibres and films, the cavities in which are lacunar blood spaces, and are filled with blood corpuscles, &c. In the basal portion of the lamella the muscle which underlies the epithelium may be seen to be continuous with the muscle of the mantle.

At intervals along the mantle edge there are to be found papillæ, probable tactile in function, sunk beneath the surface. The papillæ are on an average about ·35 mm. long, and about half that in breadth. They are conical in shape (Pl. CLI. fig. 31), and spring from a broadened base. They lie in pits, which are sunk beneath the surface about half a mm. The pits are slightly broader than the papillæ, and have a narrow outlet to the exterior. In some sections the papillæ can be seen cut tangentially when it is seen to be completely surrounded by the mantle tissue. The walls of the pit and of the papillæ itself are covered with epithelium, which is continuous with the epithelium lining the dorsal and ventral surface of the mantle. In *Patella vulgata* they are about 100 in number, arranged apparently in a single row.

The epithelium of the dorsal wall of the mantle, just before it bends inwards to form the pit, is very regularly columnar. The cells are widely separated by cement substance (Pl. CLI. fig. 32), which spreads out over the surface to form a cuticle, with which the free ends of the epithelial cells are fused. The nuclei are oblong. The epithelium covering the pit walls and the papilla is very irregular. The cells are widely separate and irregularly columnar. The surface of the papilla is much corrugated, and the epithelium is thus thrown into folds which run circularly round the papilla. The epithelial cells are attached by fine processes to the subjacent tissue (Pl. CLI. fig. 33). The centre of the papilla is composed of muscular fibres running longitudinally in the papilla, and spreading in a fan-like manner, so as to unite with the epithelium with their ultimate fibrillæ. The muscle fibres are continuous with those of the mantle. The very centre is occupied by a large nerve. There is a nerve plexus, more or less distinct at the root of the papilla.

The papilla lies nearer the ventral side of the mantle, and the inside wall of the pit on that side is lined by squamous epithelium.

(*b*) *Renal System.*—The kidneys (nephridia) are two in number, right and left. Their position and relationship have been more fully worked out than

most other parts. There are, however, points in their anatomy and histology which do not appear to have received sufficient attention.

The left nephridium is by far the smaller of the two, and occupies the triangular space between the pericardium and the terminal portion of the rectum. It is bounded above by the visceral integument, and beneath by the dorsal wall of the subanal portion of the left nephridium; to the right it is bounded by the wall of the rectum.

The left nephridium communicates with the pericardium by a minute canal. On laying open the pericardium, the opening of this canal may, in specially large limpets, be seen (Pl. CLI. fig. 36). The one from which the figure is taken was about $2\frac{1}{2}$ inches long with the shell removed. A split bristle was inserted into the aperture, and on dissection was found to have penetrated into the cavity of the left nephridium. The pericardial opening was situated just beneath the attachment of the auricle, and very near the front wall of the pericardium. It lay almost in front of the much larger opening of the right nephridium. The left nephridium communicates also with the exterior by a papilla which lies to the left of the anal papilla. The left nephridium itself consists of a sac whose walls are folded and ridged to an enormous extent, so that the central cavity is broken up into a series of diverticula. The central cavity remains continuous with the duct into the pericardium on one side and to the exterior on the other. The canal leading from the pericardium to the left kidney is lined by squamous epithelium continuous with the epithelium lining the pericardium. Towards the cavity of the kidney itself the squamous epithelium becomes cubical and then ciliated, and contains granular concretions. The cilia are exceedingly difficult to preserve, and only a cell here and there showed the cilia at all satisfactorily.

The author has not been able to see the "triangular piece of tissue," described by CUNNINGHAM as functioning as a valve at the opening into the kidney, but his sections may not have been in this respect so favourable. The canal is surrounded by a quantity of connective tissue and nonstriped muscle, by the contraction of which it may be possible to occlude the canal altogether. The valve under such circumstances seems to be rather superfluous, though the writer is not prepared to say it does not exist. The folded wall of the kidney is composed of connective tissue containing a large quantity of nonstriped muscular fibre. In the connective tissue there are a large number of lacunar blood spaces; in short, as well put by LANKESTER, "the sac is practically a series of blood-vessels covered by renal epithelium." The renal epithelium is in some points difficult to make out in its structure.

It has been described as consisting of ciliated nucleated columnar cells containing small dark-coloured concretions.

So far as the author has been able to make out from a study of the

epithelium in the fresh condition and in section, the connective tissue of the folds is covered by epithelium which is in several layers (Pl. CLI. fig. 35). The lower cells are rounded or polygonal, and present a homogeneous protoplasm crowded with granules of a light green or brownish tinge. A nucleus may here and there be distinguished, but, as a rule, the density of the protoplasm, and the manner in which it is filled with concretions, prevents it being possible to do so. The upper cells of the epithelium are much larger (Pl. CLI. fig. 37), and present a large number of vacuoles. These cells are ciliated; and it has been possible in some sections to make out distinctly the cilia, although in by far the most cases they could not be made out. They are, however, visible in the fresh condition by teasing. As stated by Von JHERING to occur in Tethys, and as suggested by CUNNINGHAM in Patella, probably the process of secretion is the absorption from the blood in the lacunar spaces in the walls of the diverticula of the urinary matters, the presence of which in the cells causes them to be vacuolated. Probably, as the lower cells become so filled, they come to the surface, and burst into the lumen of the gland, where they appear as granular débris, composed partly of the remains of the epithelial cells themselves, partly of the concretions which they contained. The writer thinks he has been able to make out the successive stages in this process in sections which were found to show best mounted in balsam (Pl. CLI. fig. 37). (The subject will be referred to in detail in its proper place in Part II.) The epithelial layer varies in thickness at different points. On surface view the polygonal outlines of the cells could be distinctly seen, and in sections mounted unstained in balsam the separate cells were perfectly distinguishable.

The right nephridium is of far larger size than the left nephridium. It forms a large sac much darker in colour than the left kidney, and extending round the viscera from almost the median line above quite to the median line below, where it ends abruptly in a straight edge. It encircles the posterior part of the genital gland, and rises over the coils of the alimentary canal behind. It ends at the posterior part of the superficial coil of the intestine. In front it is bounded by the anterior body wall, but passes in the form of a long tongue behind the rectum, being bounded in that region behind by the anterior part of the superficial intestinal coil. On dissection it is found to send a corresponding tongue beneath the rectum (the "subanal tract" of LANKESTER and BOURNE), which is like the superficial tongue irregular in outline. Like the left kidney, the right has two outlets—one to the exterior and one to the pericardium. The canal opening to the exterior opens at the right renal papilla situated to the right of the anal papilla. The opening into the pericardium can be easily made out in a large specimen from the pericardial aspect. It lies beneath and slightly behind the opening of the left kidney, and appears when viewed from the interior of the pericardium as a longish pear-shaped slit lying

horizontally, the broader end being anterior. The duct connecting it with the cavity of the kidney is comparatively short and wide, and like that of the left kidney is lined by squamous epithelium, and surrounded by connective tissue and muscle. The duct soon opens into the subanal tract of the right nephridium, and then becomes lined by granular ciliated epithelium similar to that found in the left kidney. The histological structure of the right kidney is similar in all respects to that of the left, but the cells are filled with granules which are much darker in colour, though they can scarcely be said to be more numerous.

While the left nephridium partakes more of the nature of a sponge, the right is rather a sac with plaited walls (Pl. CL. fig. 34).

With regard to the comparative structure of the two kidneys, the author is inclined to think that the substances which the right kidney secretes from the blood are chemically different from those secreted by the left. The degree of solubility in certain reagents of the granular matter of the two kidneys is different, and the granules are much darker, in addition to being more numerous in the right than in the left. This subject will, however, be gone into in detail in the physiological part of the work.

Cuvier (*loc. cit.*) asserts that the laminæ dependent from the mantle are gills. Blainville denies this, and thinks the mantle over the neck is respiratory in function, owing to the number of vessels found there. Adamson, Milne-Edwards, and Gray support Cuvier's view. As above shown, both views are to be accepted as true. Dall (*Amer. Jour. of Conch.*, 1871, 268), strangely enough, says that the cordon of gills is uninterrupted; an undoubted interruption does take place at the point of entrance of the branchial vein over the left shoulder (Pl. CLI. fig. 38). Lankester (*Ann. and Mag. Nat. Hist.*, iii. p. 20, 1867), showed that Patella had two distinct kidneys, one of which, he was at that time able to show, opened into the pericardium. The opening into the right kidney was subsequently discovered by Lankester and Bourne, and the existence of the subanal tract pointed out (*Ann. and Mag. Nat. Hist.*, vii. 1881). Doubt being thrown by various observers upon certain points in Lankester's description, more especially on the connection between the left kidney and the pericardium, the subject was reinvestigated by Cunningham (*Quart. Jour. Mic. Science*, xxii. 369), who further described the form and structure of the renal organs, and confirmed Lankester's account. Williams' account of the structure of the branchiæ (as quoted by Dall in *Amer. Jour. Conch.*, 1871) the author is able to confirm and extend; the author found, however, no indication of the cilia mentioned by Williams as covering the branchiæ; nor are they, indeed, to be expected there, since the laminæ are really outpushings of the mantle wall, and not morphologically true gills, as in the cited case of the gill plate of *Anodon*.

5. *Connective Tissue System.*—The connective tissue of Patella does not call

for special mention. It consists of the usual elements, viz., connective tissue fibres, connective tissue cells, and elastic fibres. These last are few in number, and are never so distinctly definable as in the Vertebrata. Many amœboid cells are also found among the connective tissue fibres. These are usually larger than the blood corpuscles, and have long branched processes.

The presence of connective tissue has been indicated, and its general features have been pointed out under the different organs in which it occurs.

Muscular System.—The general muscular system, comprising the muscular fibres entering into the structure of the various organs, is described under the different sections where these organs are described.

The special muscular system includes (*a*) the muscle of the head and neck, (*b*) the circular muscle connecting the foot and the shell, &c., and (*c*) the muscle of the foot proper.

(*a*) The muscle of the head and neck is arranged in three layers over the dorsal surface, from tentacle to tentacle, a superficial transverse, or circular, layer, a middle longitudinal with numerous oblique fibres, and a deep transverse layer. These layers are continuous with the muscle bands composing the foot and circular muscle, and fibres from them pass up into the tentacle. On the ventral aspect the middle layer is usually wanting, though a few strands of oblique fibres are occasionally present. The outer and inner layers also are much thicker.

(*b*) The circular muscle at its origin from the shell is composed of a number of plates arranged vertically, and having their long axes parallel with the surface of the body. Their free ends where they spring from the shell are covered with a very dense layer of epithelium, which is in direct contact with the shell. The epithelium is cubical, and so closely packed that the general appearance is such as to suggest that the ends of the muscle fibres are themselves in contact with the shell, and that the epithelium is really only the denser terminations of the muscle fibres (Pl. CXLIX. fig. 6). If the epithelium covering the free part of the mantle in the head region be examined, the cubical nature of the epithelium is there clearly to be made out. The inner ends of the cells are serrated in a manner similar to the epithelium in many other parts (Pl. CL. fig. 18). The free ends are covered by a thin cuticle. The cells are continuous on the one hand with the epithelium covering the dorsal surface of the visceral integument, and on the other with that of the dorsal surface of the mantle skirt (Pl. CL. fig. 20).

The muscle plates descend vertically, branching and spreading in a fan-shaped manner, so as to cause the circular muscle to be twice the breadth at its union with the foot as it is at its origin from the shell. The outer lamellæ pass directly downwards, the inner lamellæ curve round, and are continuous with the muscle of the foot proper. These bands of vertical muscle are separated

by thin plates of oblique or circularly arranged muscle, which almost entirely take the place of the vertical muscle towards the exterior of the foot (Pl. CL. fig. 19). The fibres there are fine, and are enclosed in bundles by strands of connective tissue.

(*c*) In the foot proper, towards the margin there is an open connective tissue network, with variously arranged branching muscle fibres scattered through it, many of which are in connection with the inner ends of epithelial cells by fine processes. The upper portion of the foot, which forms the floor of the visceral sack, is composed of the horizontal or oblique plates of muscle continued from the circular muscle. The ventral portion is composed of a network of connective tissue fibres, amongst which are found a large number of horizontal, vertical, and oblique muscle fibres.

The connective tissue is dense on the ventral surface, especially just beneath the layer of epithelium. The cells of the epithelium are continuous with those of the side of the foot, but are much crushed, and often wanting in section. There are no glands of any kind in the foot.

In the head region, where there is no circular muscle, the muscle fibres which sprung from the shell are continued into the free skirt of the mantle (Pl. CL. fig. 20).

The individual muscular fibres of which the bands of muscle are made up, are of the nonstriped variety. Each cell is a very long fibre, often as much as $\frac{1}{8}$ of an inch in length, while the breadth is about $\frac{1}{4000}$ of an inch. The fibres do not branch, but are collected in fasciculi with a small amount of cement substance between. Each fasciculus is surrounded by a small quantity of connective tissue. The fibres themselves are perfectly homogeneous or faintly fibrillated (Pl. CL. fig. 21).

Epidermal System.—The visceral dome is entirely covered by an integument which is easily detachable, and which is composed of two or three layers according to the position.

Externally (Pl. CXLIX. fig. 4) is a layer of dark pigment cells, then a layer of connective tissue, and internally (in those parts where it covers the nephridia) a layer of light pigment cells.

The external pigmented cell layer consists of a single layer of tabular or cubical cells, each containing a round or elliptical nucleus, with one or two nucleoli. On vertical section, the outlines of the cells can be distinctly made out, but they are not so easily seen on surface view. In such a surface view as that represented in Pl. CXLIX. fig. 5, the nucleus is seen to be surrounded by a quantity of pigment in the form of rounded black granules. In other situations the granules do not surround the clear nucleus, but lie between it and the upper part of the cell, which is hyaline in appearance, but possesses no cuticle. As the edge of the dome is reached, the pigment is wanting, and there appears

over the cells a delicate homogeneous highly refractile cuticle. Just before the circular muscle, the cells for a short distance become spindle-shaped, and lie on their sides (Pl. CXLIX. fig. 6). The fine processes of these cells fuse with the cuticle on one side, and with the subjacent connective tissue on the other. Over the circular muscle the cells are cubical and densely packed, and set directly on the ends of the muscle fibres. Over them there is a tolerably distinct cuticle. These cells are continuous with the epithelium of the dorsal surface of the mantle. Where the pigmented epithelium is absent, as at the top of the dome, there is a layer of squamous epithelium forming a superficial covering to the middle layer of connective tissue.

The second and main layer of the visceral integument consists of a feltwork of connective tissue fibres and branched connective tissue corpuscles. A few fibres of a more highly refractile nature may be seen which are probably elastic in their nature. The middle layer is divisible into two chief layers, one of which allies itself to the superficial pigmented epithelium, the other to the deep pigmented epithelium when that layer exists. Each layer is composed of several finer layers separable by pressure or teasing. The fibrils of which each layer is made up are extremely fine, and are united by a gelatinous and in some places granular matter into thin films. Connective tissue cells and nuclei are scattered irregularly among the fibres.

The third layer consists of a single layer of large cubical cells which are polygonal in outline on surface view (Pl. CXLIX. fig. 7), and contain nucleus and nucleolus, and a large number of greenish-yellow granules. These cells really form the superficial layer of the right nephridium, but are usually found adherent to the visceral integument when that is removed. The author has not been able to make out any squamous epithelium on those parts of the inner surface of the integument not covered by this pigment layer.

The integument of the side of the foot (Pl. CXLIX. fig. 8) is composed of cells similar to those found on the tentacle. Near the origin of the mantle the cells are low columnar; they increase in size as the lower edge is approached, and on the lower half they are thrown into ridges as in the tentacle. The cells are there very long, with nuclei near their centres, and with a cuticle externally. The upper part of the side of the foot sometimes bears permanent ridges, composed of outpushings of subepithelial tissue, covered by columnar cells, much longer than those covering the side of the foot in that region. The dense layer of connective tissue found beneath the epithelium in the tentacle is in this situation very scanty; and beneath it is a series of vacuoles, or lacunar spaces, between the trabeculæ which pass from the general muscle of the foot to be connected with the ends of the epithelial cells.

The epithelium is continued round the edge of the foot for a short distance, in the form of long columnar cells, which soon, however, become modified into

a granular crushed layer, very irregular, and resting on a dense layer of connective tissue. The epithelium, at least in sections, most commonly falls off, and leaves the subjacent connective tissue exposed.

Over the head and neck the columnar epithelium is composed of large cells which have distinct nuclei. The subepithelial connective tissue layer is very evident, and fibres are seen passing through it to the epithelial cells (Pl. CXLIX. fig. 9). On surface view the cells present a granular mosaic.

Protective System.—Under the head of protective system may be classed the mantle, whose function in this relation is to afford protection to the functional gills and the shell. The mantle has already been described under the respiratory system.

The shell, as has been already stated, is dome-shaped, and has ventrally an oval outline (Pl. CL. fig. 22), the narrow end being anterior. The apex of the dome is blunted, and the outline of the sides is curved. The apex of the dome is nearer the anterior end (Pl. CL. fig. 23).

Externally two series of lines are visible on the shell—(*a*) a radiating series from the dorsal apex to the edge; (*b*) a series concentric with the ventral edge. The lines are of various degrees of coarseness, and some are nodulated and tuberculate.

Internally, the radiating lines are represented by bands of blue and yellow of variable shade and width. These bands are crossed at intervals by concentric bands of dark colour more or less distinct in different individuals.

The rim of the shell is chisel-shaped, the bevelled side being inwards. The shell rapidly thickens from the edge, and then maintains a tolerably constant thickness throughout. The edge is sharp and notched.

The pallial line is visible as a pale belt of variable width (usually $\frac{1}{8}$ inch) running in a sinuous manner along the shell about $\frac{1}{4}$ inch from its edge (Pl. CL. fig. 22).

Inside the mantle line at a short distance is the impression of the attachment of the circular muscle connecting the foot and the shell. The impression is divided, as is the muscle itself, into more or less distinct areas. The breadth of the belt is tolerably constant (usually about $\frac{1}{6}$ inch.) The most anterior muscle impression, one each side, is larger, and rounded anteriorly. The inner border of the belt is more irregular than the outer.

Within the impression of the circular muscle there is a belt of irregular breadth and outline, generally broadest posteriorly. The belt marks the attachment of the integument of the visceral dome. The impression expands in front, and fills up the space left vacant by the absence of the circular muscle impression. That space is about one-sixth the entire circumference of the shell at that level. The remainder of the concavity of the shell is not touched by the derm of the visceral dome. It is usually white, and lacks the lustre of the

other parts of the inside of the shell. The entire shell is translucent, though the portion round the apex tends to become opaque.

The microscopic structure of the shell is extremely difficult to determine accurately. If it be soaked in strong nitric acid for some time, a series of laminæ may be peeled off, each lamina being apparently made up of a network, or meshwork, of very fine fibres. The superficial laminæ have much wider meshes than the deeper laminæ.

A vertical section through the entire shell presents three layers, the middle layer above extending from edge to edge (Pl. CLII. fig. 46). The inner layer is found only beneath the dome, and, under the low power, presents itself as a granular, more or less structureless film, occupying mainly that portion of the shell not touched by the derm of the visceral mass. The outer layer, which also appears granular, carious, and pigmented, extends over the entire surface, save the extreme borders. This layer, when examined under a higher power, is found to be perforated in every direction by minute canals (Pl. CLII. fig. 49). These canals are not more than $\frac{1}{1000}$ of an inch in diameter, and branch and anastomose to such an extent as to give that part of the shell the appearance of yellow elastic cartilage, or the framework of a sponge. The canals are much more abundant towards the surface. The canals break into one another, and thus form larger canals varying in size according to the number of small canals which have gone to form the larger. The small canals are long, unbranched, and straight, and much fewer in number as the middle layer is approached. Indeed, there can scarcely be said to exist three distinct layers; the inner and outer layers being simply the middle layer under different conditions of growth or decay. The middle layer itself is composed of long, branching, polygonal "cells" or rods, whose long axes lie at right angles to the outer surface of the shell. Each rod is made up of a large number of febrils, lying parallel to the long axis of the rod, and the rod has in consequence a striated appearance. In section the rods are polygonal, round, oval, or irregular; they are separated from each other by a cement substance, which forms the reticulum left after the removal of the mineral matter by the nitric acid. This substance, which is fibrillated, is stained yellow by the acid, and is therefore probably animal in its nature. These rods are crossed, especially towards the border of the shell, by lines indicating the successive laminæ of deposition. The arrangement of the various elements will be best understood by reference to the figures (Pl. CLII. figs. 46–49).

The inner and middle layers are perfectly colourless; the outer layer has yellowish-green and brown pigment granules deposited in the canals by which it is perforated. The bands of bluish-grey, usually seen on the inner surface of the shell, are therefore not due to pigment, but probably to the peculiar arrangement of the rods, and the effect of light upon them. On the inner

surface of the dome, however, at the very apex, the inner layer becomes impregnated to a slight extent by pigment granules.

It is very doubtful whether the caries on the surface layer of the shell be a natural condition; the author is inclined to think that it is due to a parasitic growth, and that the pigment is foreign matter, either belonging to the parasite or introduced from the surrounding water into the canals formed by it. This view is supported by the fact that in some places the shell is much more decayed than elsewhere, and that some shells, though younger, are more carious than others which are obviously of older growth. The shells examined were of course not fresh, and so any possible inhabitant of these tubes could not be detected. In the physiological section of this research, the subject will be reinvestigated. Irrespective of the possible truth of the explanation above suggested, it will be interesting to know what conditions are necessary for the formation of this caries, and what are the agents and *modus operandi* employed.

The general appearance of the shell has been described very frequently; indeed, in the older accounts of *Patella* the shell was the only part which was described with anything like completeness. Carpenter, who, so far as the writer is aware, alone has studied the shell microscopically, says that it consists of three layers, inner and outer layers less compact, and a middle layer of polygonal or prismatic cells.

Dall (*loc. cit.*) quotes Williams as saying that "the lining membrane of the branchiæ is continuous, and therefore that it is highly improbable that water penetrates into the circulatory system, as in some other molluscs." With reference to that statement, it may be well to remember the nature of the epithelium lining the branchiæ, as indicated above (*vid.* "Respiratory system").

Reaumur mentions the existence of glands in the foot, and Born (*loc. cit.*) says there are tubercles in the same organ; and these authors affirm that from these glands, or tubercles, there exudes a glue, by which the animal fixes itself to the rocks. Adanson also speaks of suckers on the pedal surface; and Adams (*Recent Mollusca*, i. 465) asserts that the cavities which the limpet not infrequently makes in some kinds of rock are made by spicula with which the foot is provided. The writer has not been able to find the slightest indication of glands, either beneath the surface or in tubercles; nor has he been able to see anything that could be mistaken for a sucker or a spicule of any kind whatever, although he made a very thorough examination of the foot, not only by superficial search, but also by many microscopical sections.

6. *Nervous System.*—The nervous system is exceedingly complicated, but, with moderate care, it may be dissected out in its entirety.

There are altogether no less than eight pairs of ganglia; only three of these, however, are of primary importance, viz., the cerebral, visceral, and pedal (Pl. CLII. fig. 50).

The cerebral ganglia are large irregular nervous masses, situated deep down, just at the base of the tentacles; the visceral and pedal ganglia lie close together just at the anterior edge of the floor of the visceral cavity. The cerebral ganglia are found to give off (*a*) nerves and (*b*) commissures. The nerves are four in number, on either side. (The nerves of the left cerebral ganglia only are here described, those of the right being precisely similar.) First, the tentacular nerve, which arises from the anterior left corner, and passes directly into the nuchal tentacle. This nerve very soon divides, giving off numerous branches to the muscles and skin of the tentacle. Just at its base anteriorly arises a small nerve, the cutaneous, supplying the skin of the neck and snout. Immediately behind the origin of the tentacular nerve is the optic nerve, which is not a branch (as might be supposed) of the tentacular, but is an entirely distinct nerve, going directly to the eye. The nerve divides repeatedly ere reaching the eye, and loses itself in a nervous plexus, immediately behind the retina. All these nerves spring from the outer aspect of the cerebral ganglion. On its inner aspect, immediately opposite to the origin of the optic nerve, is a small nerve supplying the muscles of the pharynx, and which may be termed therefore the posterior lateral pharyngeal nerve. In addition to these nerves there are a number of commissures uniting the cerebral ganglia to the rest of the system. The anterior end of either ganglion gives off two commissures, one passing in front of the buccal mass, and easy to find, the other passing vertically up the side of the same, and more or less involved in muscle and connective tissue. The former is a large thick white commissure which runs in front of the œsophagus, far forward. It unites the two cerebral ganglia. After leaving either ganglion the commissure is slightly swollen, and at that point it gives off a nerve, which, since it supplies the anterior muscle of the pharynx, may be termed the anterior lateral pharyngeal nerve. In front the commissure gives off many small nerves which supply the lips. At the point where the anterior pharyngeal is given off a nerve loop encloses the commissure, coming from below upwards and passing backwards. It is not connected in any way with the commissure. Following now the second commissure, which springs from the cerebral ganglion, we find it mounts the side of buccal mass, and becomes united to a small ganglion lying at the side of the pharynx and on the top of the muscles of the infraradular sheet. This ganglion is one of four which lie at the angles of a square formed by the commissures which unite them, *i.e.*, along either side of the pharynx. On the top of the muscles of the infraradular sheet there are two ganglia united to each other and to their fellows on the opposite side. These ganglia are the superior, anterior, and superior posterior buccal ganglia respectively. To the anterior ganglion on either side is united the end of the loop spoken of above as enclosing the cerebral commissure. The commissures uniting the

two anterior and the two posterior ganglia to each other lie between the pharynx and the muscles of the infraradular sheet. Tracing the loop above mentioned round the cerebral commissure, it is found to bend suddenly backward, and to unite itself with a small ganglion on a second cerebral commissure which lies beneath the buccal mass. These two small ganglia on this second commissure have been considered as inferior buccal ganglia; and, since the nerves from them supply the ventral protractors of the odontophore, they may be so named.

From the posterior part of either cerebral ganglion two slender white commissures pass backwards along the sides of the neck—the exterior to join the visceral ganglion, the interior to join the pedal ganglion. The pedal and visceral ganglia form one thick hoop of nerve matter rather than four ganglia unitedly commissures. The visceral ganglia are, as already stated, united to the cerebral ganglia by slender commissures, to the pedal by a thick short band. They give off two important nerves on either side of the body,—first, externally, the musculo-pallial nerve (which soon splits into two branches, which go to supply the branchiæ and mantle and the circular muscle respectively); and, internally, the splanchnic nerve. This splanchnic, soon after it leaves the ganglion, gives off a delicate nerve which travels back along the pharynx, and may be termed the recurrent nerve. The left splanchnic itself mounts the left shoulder, passes beneath the salivary glands, and, crossing the right splanchnic, gives off a minute branch to the right ctenidium; *i.e.*, the right ctenidium is supplied by the left splanchnic. The nerve then crosses back and unites on the way with the right splanchnic. The combined nerve gives off a number of branches to the viscera as it goes; and finally, crossing over to the left side once more, it supplies the left ctenidium. (We are indebted to SPENGEL for this discovery, and for the important suggestion that accompanies it, viz., that these ctenidia are really the rudiments of the lost true gills.) SPENGEL describes a minute ganglion, the olfactory ganglion lying near the ctenidia; that the writer has not been able, however, to see.

The pedal ganglia lie between the two visceral ganglia, close together and united by a very thick and short commisssure. They are united, as already stated, to the cerebral ganglia by long slender commissures, one for either ganglion. They give off into a slit in the muscle of the foot two large nerves each, one of which supplies the deep muscles of the foot, the other the superficial muscles.

Both the pedal and musculo-pallial nerves divide ultimately into a large number of secondary branches.

The histological structure of the nervous system is extremely simple. The nerves are composed of fibres, each of which is a very elongated, nucleated, cell. The cell itself is band-shaped and fibrillated, nucleus oblong, taking on a deep

stain, and exhibiting a nucleolus in its interior. These fibres are collected in bundles, and among them, *i.e.*, between the individual fibres, are a number of bipolar spindle-shaped cells. These cells are provided with nucleus, nucleolus, and a small quantity of granular protoplasm prolonged at either end of the spindle into long and delicate threads (CLII. fig. 51).

Both cells and fibres are enclosed in a sheath of ordinary connective tissue, usually one cell thick. The nuclei of the connective tissue corpuscles and fibres are very evident, and quite distinguishable from the nuclei belonging to the nervous elements.

The ganglia are composed of a framework of neuroglia of the ordinary nature (a very delicate connective tissue), with a very large number of nerve cells. The great majority of these cells are small triangular or irregular masses of protoplasm, with short branching or unbranched processes. The cells contain nuclei and nucleoli, and take on a deep stain.

The cells are usually much more abundant towards the surface of the ganglia, and this is more especially the case with the cerebral ganglia. The cells (round) also run up the sides of the principal nerves for a short distance as a distinct layer beneath the sheath.

In some places, more especially in the pedal and visceral ganglia, there is an abundant admixture of long bipolar cells. This may be owing to the almost undifferentiated nature of the ganglia and commissures in that situation. The author has not been able to ascertain definitely the connection between the cells of the ganglion and fibres of the nerve.

In some positions, notably in some parts of the pedal and visceral ganglia, and also in the buccal ganglia and their longitudinal commissures, there are present a number of yellow or orange granules, which appear to be immediately within the connective tissue sheath. These give to the parts where they are present a yellowish-orange hue.

Touch.—The special organs of touch are the tentacles—two in number—situated on the right and left sides of the neck. Each in its contracted condition is about $\frac{1}{8}$ inch in length, but it may be extended to from four to eight times that length. At the base they are about $\frac{1}{16}$ inch in diameter, and taper to a bluntish point. When examined with a hand lens, they appear corrugated and pigmented, especially towards the tip. About $\frac{1}{20}$ inch from the base, a small pit can be made out, on the outer aspect of either tentacle. The pit is filled with pigment, and has its open mouth pointing towards the tip of the tentacle. It is ocular in function, and is described below. The tentacle consists essentially of a mass of connective tissue in which are embedded longitudinal and transverse muscular bundles. In the centre are one or more nerves. The outer surface of the tentacle is covered by epithelium, consisting of a single layer of columnar cells (Pl. CXLIX. figs. 10 and 11).

The cells are narrow and tapering. The nuclei are long, and usually contain two nucleoli and granular protoplasm (Pl. CXLIX. fig. 12). The cells are slightly swollen in the position of the neuclei. They spring from a more or less homogeneous layer of dense connective tissue, which acts as a basement membrane. The epithelial cells are connected to this layer by fine processes, which give their inner ends a serrated appearance. The connection can, however, be easily made out in their sections under a high power. The cells are not closely arranged, but leave spaces between, filled probably with cement substance, so that a greater degree of contraction and extension is thus attainable in the tentacle. The outer ends of the cells are widened somewhat, and become continuous with a homogeneous and relatively thick (in the contracted condition) cuticle, which is highly refractile, stain bright yellow with picric acid, and is therefore probably elastic in its nature. The cuticle on its under aspect is lined by a layer of granular protoplasm formed apparently by the fusion of the ends of the epithelial cells. The epithelial cells become more cubical nearer the base of the tentacle. The subepithelial connective tissue layer is not so apparent at the tip of the tentacles, where the distinctly tapering epithelial cells are seen to be continuous with fibres in the mass of the tentacle. In the thicker part of the tentacle the subepithelial layer may be seen to give off fine processes, similar to those which connect the subepithelial layer to the epithelial cells, to join the feltwork of connective tissue of the body of the tentacle (Pl. CXLIX. fig. 14).

At the tip of the tentacle the connective tissue layer immediately subjacent to the epithelial layer is pigmented, the pigment being in the form of minute rounded granules. No pigment is found in the epithelial cells in that position.

The muscle of the tentacle is disposed in a longitudinal manner, running from the base to the tip (Pl. CXLIX. fig. 11). The muscle fibres are arranged in loose irregular strands, which may be seen to branch and unite again at intervals. There is a tolerably distinct layer of longitudinal fibres beneath the epithelial cells, especially on the outer aspect of the tentacle, the larger fibres being ventrally placed. There are many transverse fibres, not arranged in any definite bundles; also a few oblique fibres. There are no circular fibres, nor are they required. The muscle fibres are of the type described under the muscular system.

Connective tissue, and a reticulum of connective tissue corpuscles, fill up the rest of the body of the tentacle. The connective tissue is of the ordinary type, a dense feltwork of homogeneous and fibrillated fibres against and among which lie many nucleated connective tissue corpuscles. One or more nerve branches are found occupying the centre of the tentacle. Each is made up of a bundle of very fine wavy fibres, amidst which may be seen minute red-stained nuclei. The nerves branch and give off fibrils to the bands of muscle.

On transverse section (Pl. CXLIX. fig. 12) the relation of the muscle to the connective tissue can be more distinctly seen. The bands of muscle underlying the epithelium are observed as rounded areas, each surrounded and clasped by a number of connective tissue cells. Sometimes one area only is so enclosed occasionally many such are clasped by one cell, whose neucleus is seen as a bulging at one point. There are a large number of trabeculæ composed of connective tissue fibres and cells which spring from the homogeneous sub-epithelial connective tissue, and passing inwards lose themselves in the general feltwork of the body of the tentacle. The transverse bands of muscle are specially numerous in the distal portion of the tentacle. The wrinkles are for the most part temporary, but there are some where the epithelium lining the valleys differs from that covering the ridges.

Numerous very fine fibrils are seen among the connective tissue and muscle. As they are highly refractile, they are probably elastic in their nature.

A fortunate transverse section may show the epithelial cells in surface view (Pl. CXLIX. fig. 13). They form in such an aspect a mosaic. The outlines of the individual cells are roughly hexagonal or polygonal. Their ends are granular, and seem embedded in a clear membrane. Probably the cuticle is a secretion of the cells, and is therefore made up by a fusion of a number of distinct areas, each corresponding to the end of one epithelial cell. The epithelial cells themselves are not close together. They do not touch, hence the spreading appearance presented by their outer ends on longitudinal section, and their isolated appearance on end view. The tactile papillæ of the mantle are described under the respiratory system.

Sight.—The eye lies at the base of each tentacle, and consists of a small indentation or pouch which resembles the scar of a fallen leaf. The centre of the pouch is apparently filled with a black pigment. On longitudinal section of the tentacle, a distinct bulge is visible in the position of the eye, with a secondary bulge of lesser size below the large one (Pl. CXLIX. fig. 15). The large bulge forms the thick roof of a cave which is lined on its upper (roof) surface by pigmented epithelium. The cave is perfectly open to the exterior, and its mouth points forward. The swelling or bulge is very vacuolated, there being large oval and irregular spaces amongst the connective tissue (Pl. CXLIX. fig. 15). The epithelium covering the bulge is continuous with the epithelium covering the general tentacular surface. The cells are, however, slightly longer, and are separate from each other, save near the edge of the cave, where they are more crowded together. As they enter the cave they increase in length, and again become wider apart. Among the long epithelial cells of the outer surface of the ocular swelling are to be found a few cells which spring by many processes from the basement layer, and after swelling out and containing at that point a large round nucleus, terminate among the

epithelial cells in a fine-pointed end (Pl. CXLIX. fig. 14). The epithelium of the surface is continuous with the epithelium lining the ocular pit. Just after turning the edge of the pit the cuticle becomes thicker, and then becomes split into two layers, which are farthest apart at the bottom of the pit, but which are connected throughout by a series of columnar fibres which pass directly from upper to the lower layers (Pl. CL. fig. 16). The cuticle is therefore replaced by a latticework bounded on either side by a cuticle. The fibres are straight and homogeneous. They vary in thickness from the finest threads scarce visible to columns about half as thick as a columnar cell. From the outer layer of the cuticle and projecting into the cavity of the pit, are a number of very fine fibrils of variable length. They are extremely delicate, and are often destroyed in the section-cutting. The inner layer of the cuticle, which is much thinner than the outer and not so hyaline in appearance, is continuous with the ends of long, narrow columnar cells, which are longer than those of the surface of the ocular swelling. Their basal extremities taper to fine fibres, and become lost in a dense feltwork (often so dense as to appear homogeneous) which underlies the epithelium. The upper half of these cells is pigmented, the dark granules of pigment being arranged round the cell, not generally in the protoplasm (Pl. CL. fig. 16*a*). The nucleus occupies the lower half of the cell, and is long and contains many granules. The general protoplasm of the cell also is very granular.

Continuous with the subepithelial layer is a dense network of fibres and of cells, which are probably nervous. A secondary pit in the floor of the eye pit is usually to be seen, but it contains no pigment, and the cuticle has here regained its single nature and uniform thickness. Beneath the ocular swelling, a secondary swelling is situated; a pit similar in form to that just described is present, but neither the cuticle nor the epithelium show the differentiation mentioned as occurring in the true ocular pit.

The connective tissue of the ocular pit and of the secondary pit is loose, and presents large vacuoles. (The relation of the eye to the nervous system is discussed under the *Nervous system.*)

The most important researches on the nervous system are those of Brandt, Spengel, Fraissé, and Lacaze Duthiers.

Brandt (*Bull. Acad. St Petersburg*, 1869) gives a very full account of the nervous system, describing in detail the system of buccal ganglia. His account does not differ in many respects from that given above. He has, however, fallen into error more especially with regard to the arrangement of the visceral nerves. The recurrent nerve, also, he makes to spring from the musculo-pallial, whereas it springs from the splanchnic. Spengel (*Zeit. f. wissen. Zool.*, xxxv. 382) has an important statement in reference to the arrangement of the visceral nerves, and to their relation to the ctenidia, which has already been

noted. He has also described the olfactory organs, which lie in close relation to the ctenidia. FRAISSÉ's account of the eye of *Patella cœrulea* (*Zeit. f. w. Zool.*, xxxv. 461) agrees generally with that given above for *P. vulgata;* the chief difference seems to be that, in *Patella vulgata*, the "cuticularsaum" is double. In both species the outer surface of the cuticle is provided with a number of cilia—the "Fäserchen" of FRAISSÉ. LACAZE DUTHIERS' investigations into the nature of the auditory organ (*Arch. Zool. Exper.* i.) will be referred to subsequently. With reference to the sense of touch, CLARK (*loc. cit.*) mentions but does not describe the minute tentacles (or "cirrhi," as he terms them) on the mantle edge.

7. *Reproductive System.*—The male and female reproductive elements are developed in separate individuals. The glands are single, and pour their contents, when ripe, into the cavity of the right kidney, from which they escape by the right renal papilla, together with the urinary excretions.

Male.—The male generative gland is a wedge-shaped, yellowish mass, lying on the floor of the visceral cavity, and having its thicker side towards the back and left side of the visceral mass. It is covered by a delicate membrane composed of fibres of connective tissue, covered by squamous epithelium. The gland itself is a spongy mass, less dense towards the centre. Peripherally, it is composed of a framework of connective tissue, which sends processes inwards, between which trabeculæ, therefore, are formed a large number of "nests" in which sperms are developed. The trabeculæ are covered by cubical epithelium, many layers deep, the superficial layers of which become the future sperms. The manner of their development and their general appearance is extremely like that of mammalian sperms, as described by KLEIN (*Atlas of Histology*). The cubical epithelium is composed of rounded or polygonal cells, variable as to size, but usually considerably smaller than a human blood corpuscle. The superficial cells are slightly pear-shaped, and are arranged in tufts or mounds. Each cell contains a nucleus and many granules, but a cell wall is not visible (Pl. CLIII. fig. 77).

The process of development seems to be the gradual formation of a slender filament at the attached end of the cell (Pl. CLIII. figs. 78, 79) when superficial and in its pear-shaped condition; probably at the expense of the protoplasm of the cell, the nucleus becoming the head. The appearance of the cellular tuft at what may be termed the second stage is that of a raspberry, with the individual drupes separated slightly from each other. In the next stage the tuft assumes the appearance of a sheaf of barley, the "heads" of the grain corresponding to the heads of the sperms. The entire tuft meanwhile has been growing, so that ultimately any portion of the gland examined shows a series of long strands of fibre fringed and tufted with delicate plumes.

If a single plume be next examined, under a higher power, it is discovered

to be composed of a central stalk, evidently formed by the union of the several filaments of a number of heads, which are arranged around the stalk in an extremely graceful manner. Very careful focussing, under a power of 800 diameters (after long staining), is necessary before the separate filaments can be seen (Pl. CLIII. fig. 79).

Isolated sperms show themselves to be composed, as in the case of mammalian and other sperms, of a head and tail. The head is oblong, about $\frac{1}{6400}$ of an inch in length, and about a third of that in breadth, and apparently structureless. It takes on a deep stain with picro-carmine. The tail is very slender, being not more than $\frac{1}{50,000}$ of an inch in breadth by about $\frac{1}{1000}$ of an inch long. It takes on scarcely any stain after an hour's immersion in picro-carmine; the head, meanwhile, as already stated, becoming deeply stained of a crimson colour (Pl. CLIII. fig. 80).

Female.—In principle, the structure of the female generative organ is somewhat similar to that of the male. Like the male organ, it is more or less wedge-shaped, and usually larger in size. It is covered by a very delicate membrane composed of connective tissue, and covered with squames, of which latter the nuclei are the most evident parts. The gland itself is merely a bag, with a fibrous wall puckered externally and covered by a cubical epithelium many layers deep; the superficial layers of which become free, and fill the cavity of the gland as ova. The ova are of all sizes, from that of the cubical epithelial cells to spheres which can be perfectly easily seen with the naked eye. The cubical epithelium is more abundant in certain spots, which, as in the case of the testis, may be termed "nests."

An ovum (Pl. CLIII. fig. 76) fully developed is polygonal, or, when free, rounded mass, about from $\frac{1}{100}$ to $\frac{1}{60}$ of an inch in diameter. It is covered externally by a stout capsule, structureless, or vertically striated and punctured. The protoplasm is made very opaque by the presence of a very large quantity of yolk spherules. A nucleus containing nucleolus and endo-nucleoli is always visible after staining or crushing. In the younger ova, however, it is easily seen.

Historically, with the exception of FISCHER'S researches on development, very little indeed has been done towards the elucidation of the structure of the reproductive organs. In fact, any observations made on the system have been mainly as to whether ducts are present or not, and if so, whether or not the "capito-pedal orifices" are the openings of these ducts. CUVIER (*loc. cit.*) describes and figures an oviduct, which no one since his time has been able to find. DALL thinks he has seen a duct "from the extreme left of the gland, and opening into the dendritic renal sac" (*Amer. Jour. of Conch.*, 1871, vi. 271). In another later paper, however (*Proc. Acad. Philad.*, 1876, 239), he denies all knowledge of an oviduct; he denies the very existence of LANKESTER'S "capito-pedal orifices" in the first-quoted paper, but admits in the second that they are

present in some *Patellidæ*, but denies that they occur in *P. vulgata;* he moreover thinks they are "aquiferous pores." The author's experience is that they are present, and can be seen with the greatest of ease in all limpets; that they are, as described by SPENGEL (*loc. cit.*), not "orifices" at all (and how they could be called or thought so is to him a mystery), but rudiments of the lost true gills. GRAY, in his *British Museum Catalogue*, says that the milt or roe lies on the right side; the author's experience is that in the vast majority of cases it lies on the left, although the point is of no great importance.

ROBIN and LEBERT (*Anal. de Sc. Nat.*, 1846) say that the generative gland was wanting in more than half of the specimens they examined. Without going so far as to contradict that statement, the writer must state that, in the examination of over 100 specimens, he never found the generative glands entirely wanting, although in some cases they were smaller in size. The animals examined were collected in April, July, October, and December. The writer found no indication whatever of any duct either from the testis or ovary, and therefore is disposed to believe that the reproductive glands must open at certain seasons into the right renal sac, and that they do not possess special ducts of their own.

EXPLANATION OF PLATES.

PLATE CXLIX.

Fig. 1. *Patella vulgata*, face view (× 2). *v.h.*, visceral hump; *l.r.p.* and *r.r.p.*, left and right renal papillæ; *a.p.*, anal papilla; *c.m.*, circular muscle; *t.*, tentacle; *m.*, mouth; *f.*, foot.

Fig. 2. Dorsal view, shell removed (n.s.). *m.s.*, mantle skirt.

Fig. 3. Dorsal view, visceral integument removed (n.s.). *r.*, rectum; *pr.*, pericardium; *ct.*, ctenidium; *l.*, liver; *l.n.*, left nephridium; *r.n.*, right nephridium; *c.m.*, circular muscle; *ra.*, radula; *s.i.*, superficial coil of the intestine; *g.*, genital gland.

Fig. 4. Visceral integument (× 250). *a*, superficial pigmented epithelium; *b*, median connective tissue layer; *c*, deep pigment layer (renal epithelium).

Fig. 5. Superficial pigment layer of visceral integument (× 500), surface view.

Fig. 6. Epithelium over the circular muscle-band (× 250). *a*, ordinary cells; *b*, transitional spindle-shaped cells; *d*, dense epithelium over the muscle, with cuticle; *c*, muscle.

Fig. 7. Deep epithelium of visceral integument, surface view (× 500).

Fig. 8. Epithelium covering the surface of the foot (× 350).

Fig. 9. Epithelium covering the head and neck (× 500).

Fig. 10. Transverse section of nuchal tentacle (× 500). *a*, epithelium; *b*, nerve fibres; *c*, ventral muscle band; *d*, eye.

Fig. 11. Longitudinal section of nuchal tentacle (× 50). *d*, eye; *e*, pigment in subepithelial connective tissue of tip of tentacle.

Fig. 12. Epithelium of tentacle (× 500). *a*, columnar cells; *b*, subcuticular layer of granular proptoplasm; *c*, cuticle; *d*, trabeculæ of connective tissue passing inward from *g*, the subepithelial layer of connective tissue; *f*, muscle fasciculi enclosed by connective tissue cells, *e*.

Fig. 13. Epithelium of tentacle on surface view (× 500).

Fig. 14. Epithelium from the outer aspect of the ocular swelling (× 500). *a*, cuticle; *b*, columnar cells; *c*, pointed short cells; *d*, subepithelial connective tissue; *e*, trabeculæ.

Fig. 15. Longitudinal section of eye (× 250). *a*, ocular pit and retina.

PLATE CL.

Fig. 16. Retina (× 800). *a*, cuticle with two layers. *b*, prisms separating them; *c*, pigmented epithelium; *d*, nerve plexus. (This figure was drawn from a preparation in which the cilia were wanting.)

Fig. 16*a*. Arrangement of pigment granules in the columnar cells (× 800).

Fig. 17. Transverse section through neck behind the origin of the tentacles. *ph.*, pharynx; *s.*, salivary gland; *p.*, palate; *r.*, radula; *m.s.*, muscle of infraradular sheet; *l.c.*, lateral cartilage; *a.c.*, anterior cartilage; *l.p.*, lateral protractor; *v.pr.*, ventral protractor; *u.p.*, under plate; *v.tr.* and *v'.tr'.*, ventral transverse muscles; *l.m.*, longitudinal muscle.

Fig. 18. Epithelium covering the attachment of the mantle to the shell in the head region (× 250). *a*, epithelium; *b*, subepithelial layer; *c*, muscle.

Fig. 19. Vertical section of circular muscle (× 50). *a*, epithelium; *b*, blood vessel; *c*, vertical muscle; *d*, epithelium of side of foot; *e*, circular muscle (deep); *h*, circular muscle (superficial); *f*, nerves; *g*, dense connective tissue beneath the epithelium of foot.

Fig. 20. Section of the mantle (× 50), (see fig. 18). *a*, epithelium; *b*, lacunar blood spaces; *c*, mantle muscle.

Fig. 21. Muscular fibres of foot (× 500).

Fig. 22. Shell, with muscle, &c. impressions (interior), (n.s.). *m.a.*, mantle attachment; *c.m.*, circular muscle attachment; *v.*, visceral attachment; *d.*, dorsum, not touched by viscera.

Fig. 23. Shell (exterior) (n.s.).

Fig. 24. Radial section, mantle and gill processes (× 50). *a*, papilla; *b*, nerve; *c*, efferent branchial vein; *d*, gill lamella; *e*, muscle; *f*, afferent branchial veins.

Fig. 25. Epithelium of the dorsum of the mantle (× 500). *a*, epithelium; *b*, circular muscle fibres; *c*, radial muscle fibres; *d*, connective tissue; *e*, muscle fibres connected with epithelial cells; *f*, deep radial muscle.

Fig. 26. Epithelium covering the under surface of the mantle (× 250). *a*, surface; *b*, side view.

Fig. 27. Epithelium of the mantle at the origin of gill lamellæ (× 500).

Fig. 28. Mantle, radial section, with swollen branchial vein (× 30). *a*, cavity of papilla; *b*, nerve ganglion; *c*, lacunæ; *d*, efferent branchial vein; *e*, transverse trabeculæ; *f*, radial muscle; *g*, afferent branchial vein.

Fig. 29. Connective tissue cells of same (× 500).

Fig. 30. Part of gill lamella (× 100).

PLATE CLI.

Fig. 31. Mantle papilla, longitudinal section (× 100). *a*, ganglion and nerves; *b*, nerve fibres; *c*, vascular lacunæ; *d*, blood corpuscles.

Fig. 32. Epithelium of the dorsal wall above the pit of papilla (× 250).

Fig. 33. Epithelium of papilla (× 250).

Fig. 34. Nephridia, A, left; B, right (× 50). *c*, fibrous septum; *a.a'*, blood vessels in the walls of the nephridia; *b*, left renal epithelium; *e*, right renal epithelium; *d*, cavity of right nephridium; *f*, cavity of left nephridium; *g*, epithelium of nephridia on surface view.

Fig. 35. Renal epithelium, right nephridium (× 250).

Fig. 36. Pericardium interior, looking towards the right shoulder (× 20). *a*, right renal papilla; *b*, anus; *c*, left renal papilla; *d*, pericardium; *e*, pericardial opening of the left kidney; *f*, pericardial opening of right kidney; *g*, right aorta; *h*, rectum. (This figure is semi-diagramatic, and compounded from several preparations.)

Fig. 37. Renal epithelium, left nephridium.

Fig. 38. Branchial vein and veinlets (× 50). *a*, gill lamellæ; *b*, circular muscle; *c*, common branchial vein; *d*, afferent branchial veinlets from the mantle skirt; *e*, efferent branchial veinlets from the gills to branchial vein proper; *f*, branchial vein of right side.

Fig. 39. Muscular fibres of the auricle (× 250).

Fig. 40. Pericardium (× 250). *a*, superficial clear membrane; *b*, subcutaneous connective tissue; *c*, muscular fibres attaching auricle to the pericardium.

Fig. 41. Diagramatic representation of heart and its vessels. *b.vn.*, branchial vein; *p.*, circular muscle; *b.*, pericardium; *f.*, left renal papilla; *g.*, anal papilla; *a.*, auricle; *v.*, ventricle; *d.d'.*, right and left aortæ; *e.*, left nephridium; *c.*, aur. vent. valve.

Fig. 42. Blood corpuscles.

Fig. 43. Heart and vessels, pericardium removed. (Letters as in fig. 41.)

Fig. 44. Auriculo-ventricular valve.

Fig. 45. Muscular fibres of ventricle.

PLATE CLII.

Fig. 46. Diagramatic section of shell, showing the arrangement of the laminæ.

Fig. 47. Section of shell, showing the three layers and laminæ.

Fig. 48. Do. do., magnified (× 50). *a*, upper; *b*, middle; *c*, lower layers.

Fig. 49. Superficial layer of shell.

Fig. 50. Nervous system, semidiagramatic. *ct.*, ctenidium; *p.s.b.*, posterior superior buccal ganglion; *a.s.b.*, anterior superior buccal ganglion; *i.b.*, inferior buccal ganglion; *c.g.*, cerebral ganglion; *e.*, eye; *c.c.*, cerebral commissure; *c.p.*, cerebro-pedal commissure; *c.v.*, cerebro-visceral commissure; *v.g.*, visceral ganglion; *p.g.*, pedal ganglion; *p.n.*, pedal nerve; *p.*, pallial nerve; *m.*, muscle nerve; *l.s.*, left splanchnic; *r.s.*, right splanchnic; *r.*, recurrent nerve; I., tentacular; II., cutaneous; III., ocular; IV., posterior pharyngeal; V., anterior pharyngeal; VI., labial nerves. The outer dotted and inner dotted lines represent the outlines of the buccal mass and the pharynx respectively.

Fig. 51. Nerve elements. (1) nerve—*c*, isolated fibre; (2) cells of a ganglion—*a*, rounded, *b*, bipolar.

Fig. 52. Vertical section through the nuchal tentacle, showing separate origins of tentacular and ocular nerves, and of the cerebral and visceral commissures from the cerebral ganglion. *a*, superficial layer of ganglion cells; *b*, visceral commissure; *c*, ocular nerve; *d*, tentacular nerve; *f*, epithelium of tentacle; *e*, the ocular mound; *g*, cerebral commissure.

Fig. 53. Semidiagramatic representation of intestinal coils. *ph.*, pharynx; *cr.*, crop; *a.*, anus; *r.*, rectum; *s.* and *s'.*, stomach.

Fig. 54. Face view of mouth. *a*, radula; *b*, palate; *c*, inner lips; *d*, outer lips.

Fig. 55. Section of the lower plate. *a*, cuticle; *b*, stratified columnar epithelium; *c*, connective tissue (× 50).

Fig. 56. Same, magnified (× 250).

Fig. 57. Section of liver (× 150), showing hepatic tubes cut in transverse section.

Fig. 58. Liver cells, connective tissue (× 450).

Fig. 59. Liver cells, isolated (× 500).

Fig. 60. Radula, two rows of teeth. 1 and 2, lateral teeth; 3, median tridenticulate; 5 and 4, central unidenticulate.

PLATE CLIII.

Fig. 61. Pharynx and salivary glands, dorsal neck wall removed. *a.b*, ducts of salivary gland of right side, *d*; *c*, pharynx; *e*, buccal mass; *f*, lobe of pharynx; *g*, intestine.

Fig. 62. Vertical section through neck. *a*, inner lip; *b*, upper (palatal) plate; *c*, lower (ventral) plate; *d*, pharyngeal wall; *e*, anterior cartilage; *f*, radula; *g*, ventral protractor muscle; *h*, superficial transverse muscle; *k*, longitudinal muscle; *l*, deep transverse muscle; *m*, posterior cartilage; *n*, muscles of the subradular membrane; *o*, nuchal body cavity.

Figs. 63. and 64. Dorsal and ventral views of the upper (palatal) plate.

Fig. 65. Ventral view of buccal mass. *a*, ventral protractor reflected; *b*, terminal radular plate reflected; *b'*, radula; *c*, longitudinal muscles; *d* and *e*, superficial and deep transverse muscles.

Fig. 66. Cartilages of odontophore, horizontal section, dorsal view. *a.c.*, anterior cartilage; *p.c.*, posterior cartilage; *l.c.*, lateral cartilage; *v.tr.*, deep ventral transverse muscle; *b.*, connective tissue and perichondrium.

Fig. 67. Stomach wall. The section is taken transversely through a part where the adjacent walls of the two divisions of the stomach touch.

Fig. 68. Vertical section through the visceral dome. *a*, pericardium; *b*, in the stomach; *c.c*, sections of intestine; *d*, in the right nephridium; *e*, section of rectum; *f*, left nephridium; *g*, glandular stomach, "crop"; *h*, genital organ; *k*, liver; *l*, foot.

Fig. 69. Transverse section of intestine near rectum.

Fig. 70. Cells of a follicle in glandular stomach.

Fig. 71. Glandular stomach and liver. *a*, follicles; *b*, liver sacs; *c*, bile duct.

Fig. 72. Cells of the intestine isolated and more highly magnified.

Fig. 73. One of papillæ of rectal papilla wall.

Fig. 74. Transverse section of rectal papilla.

Fig. 75. Membrane covering the genital organ.

Fig. 76. Ova, in different stages of development.

Fig. 77. Development of spermatozoa.

Figs. 78 and 79. Two stages in the development of a tuft of spermatozoa.

Fig. 80. Spermatozoa isolated.



Fig. 1.

Fig. 2.

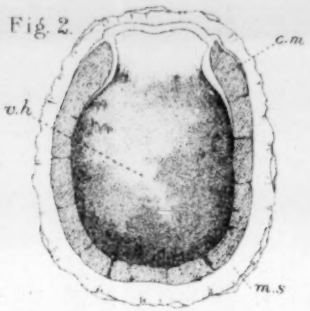


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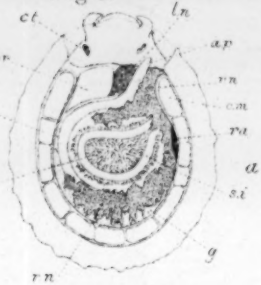




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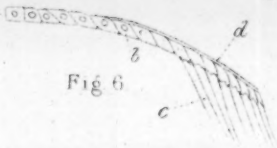
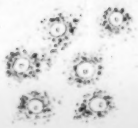


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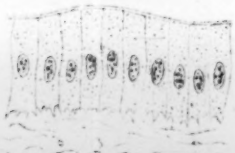


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Fig. 13.



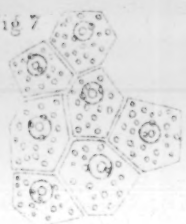


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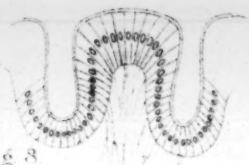


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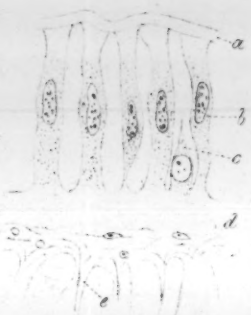


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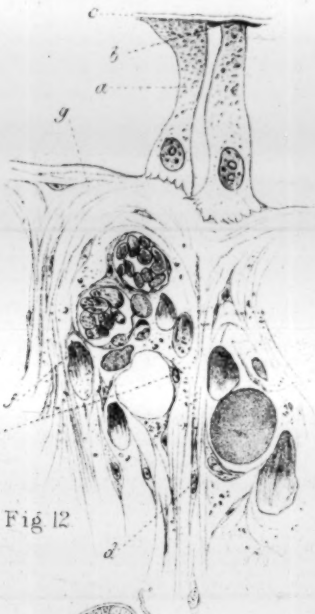


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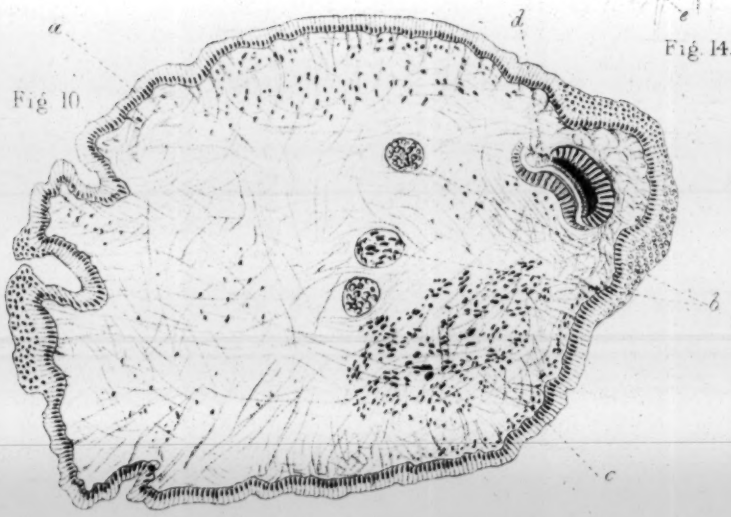


Fig. 10.



Fig. 15.

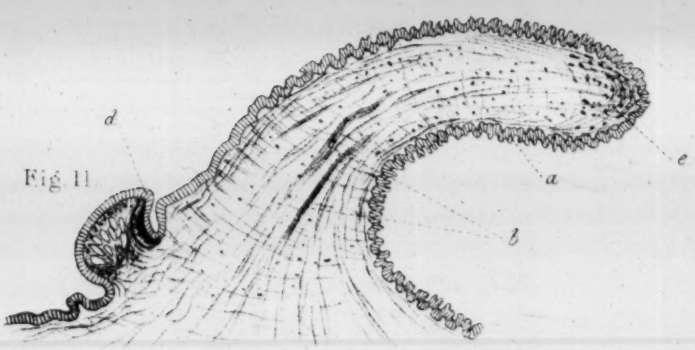


Fig. 11.

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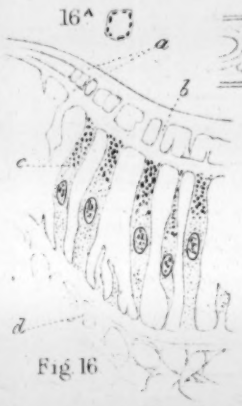


Fig 16.



Fig 20.


Fig 21.

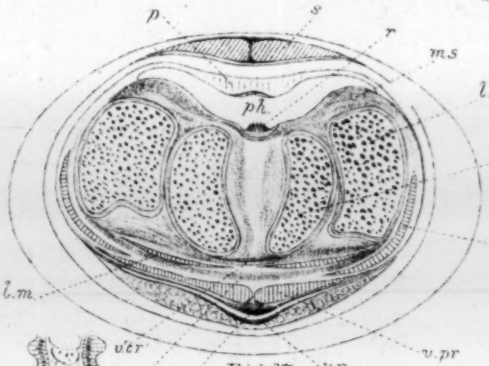


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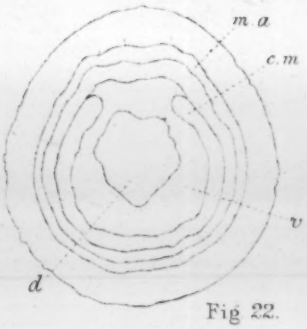


Fig 22.



Fig 18.


Fig 23.

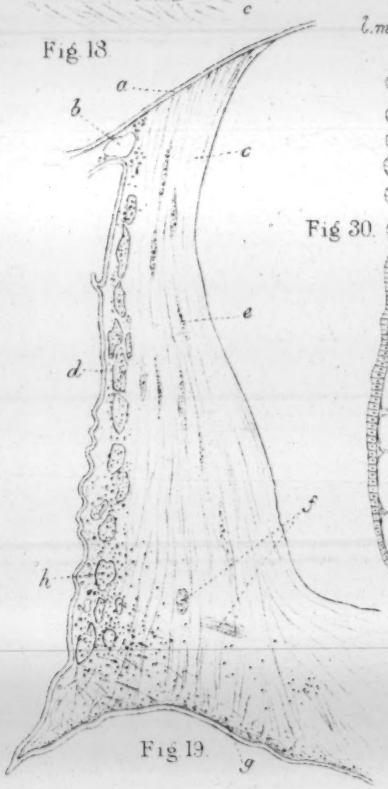


Fig 19.


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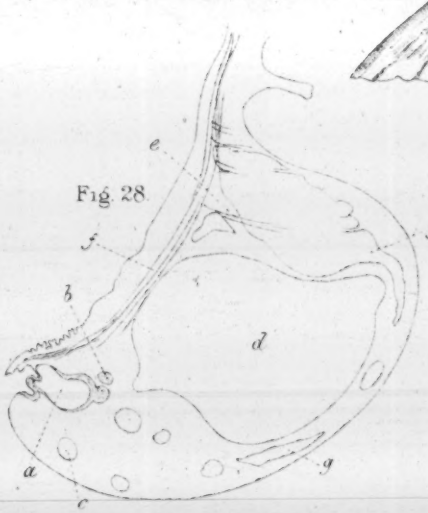


Fig 28.



Fig 24.

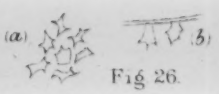
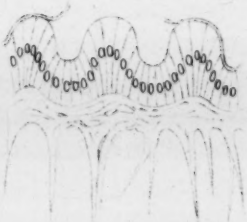


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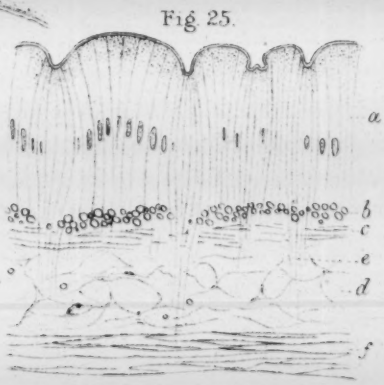
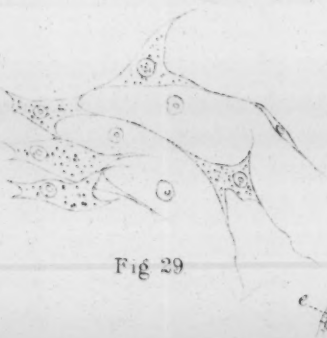


Fig 25.


Fig 29.

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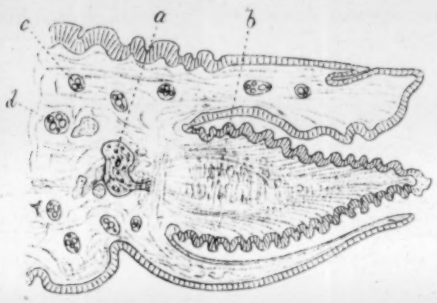


Fig. 31.


Fig. 32.


Fig. 33.

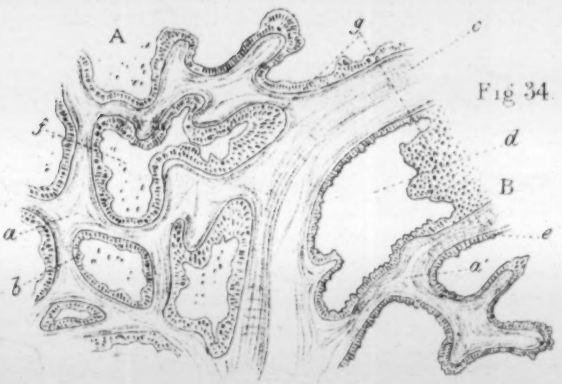
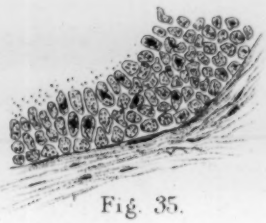


Fig. 34.


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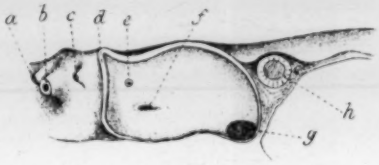


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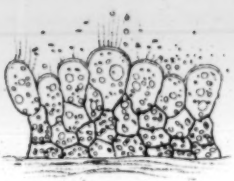

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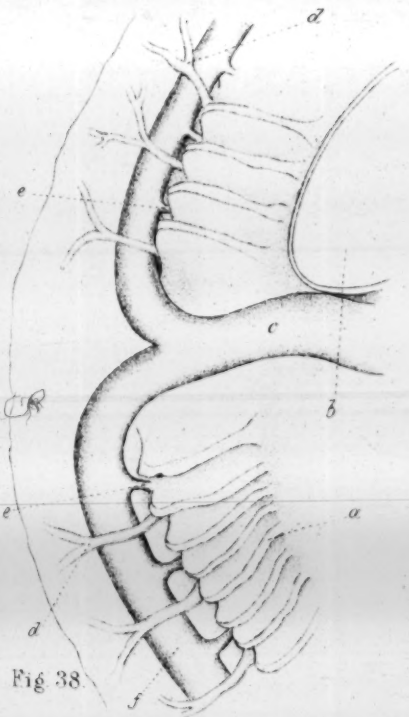
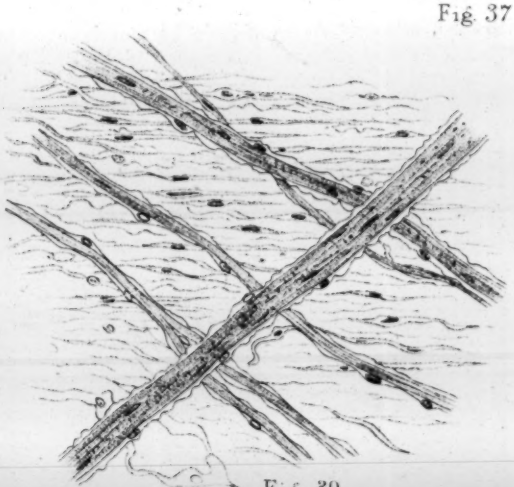


Fig. 38.


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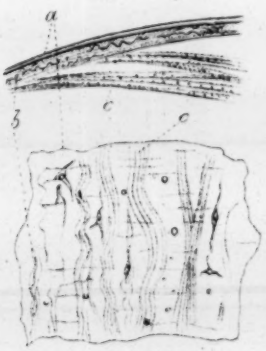


Fig. 40.


Fig. 45.

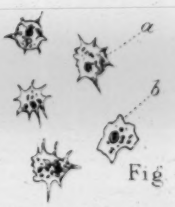


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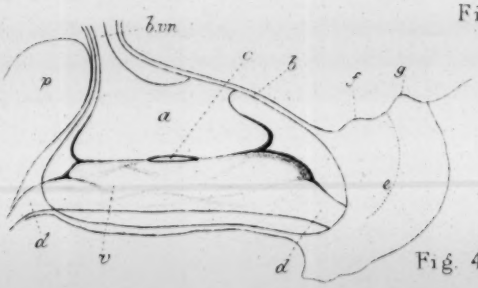


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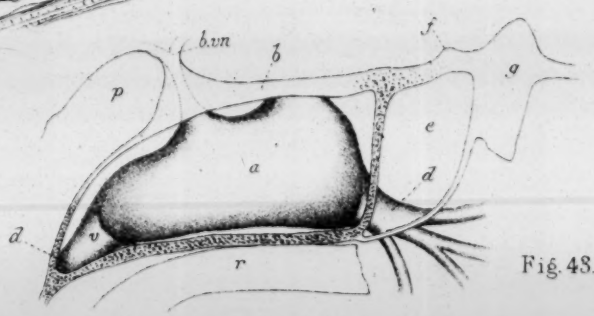


Fig. 43.



Fig. 46.

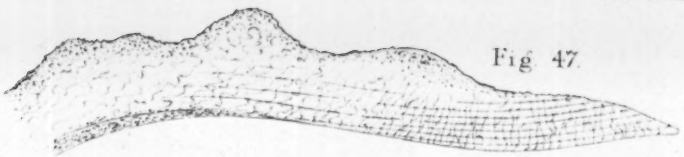


Fig. 47.



Fig. 48.

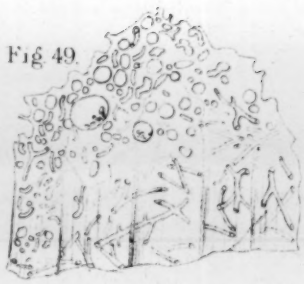


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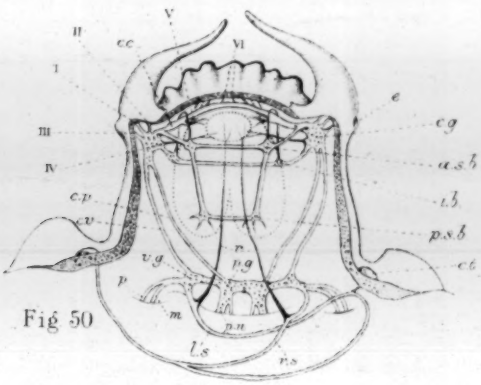


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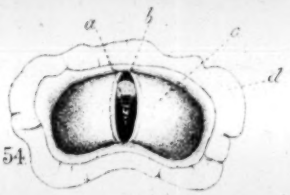


Fig. 54.



Fig. 51.



Fig. 58.



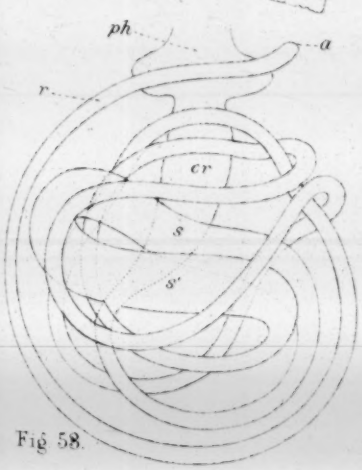


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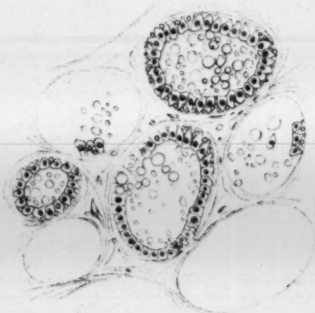


Fig. 57.



Fig. 52.



Fig. 59.

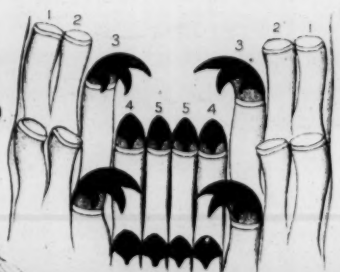


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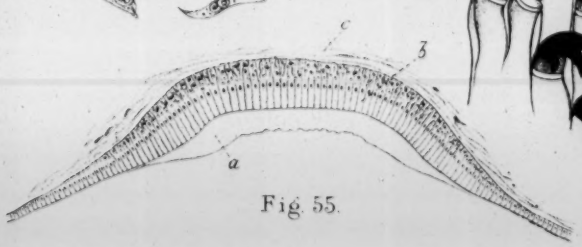


Fig. 55.

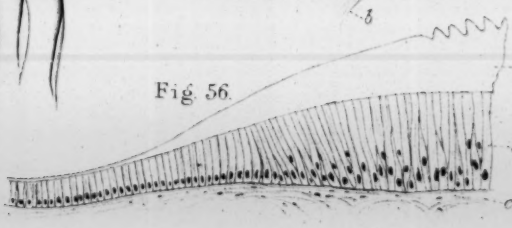


Fig. 56.

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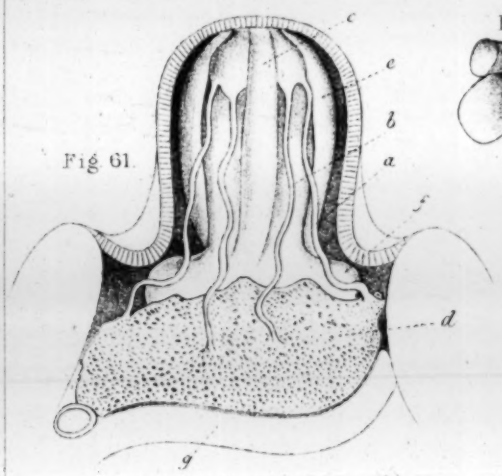
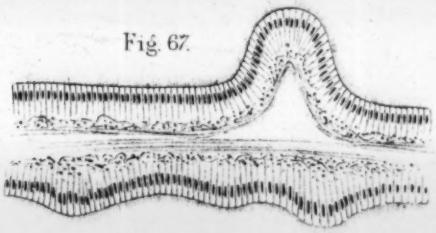


Fig. 61.


Fig. 63.


Fig. 64.


Fig. 67.

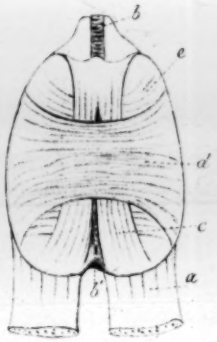


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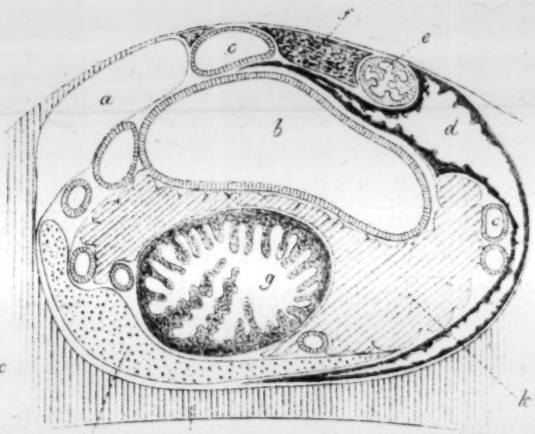


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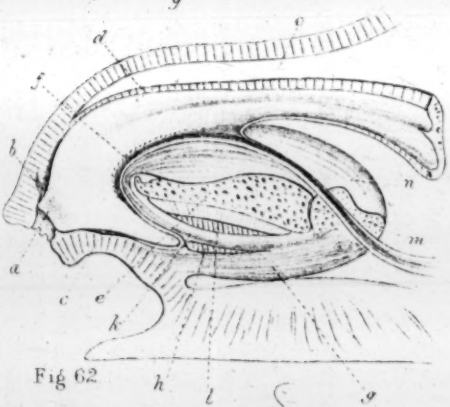


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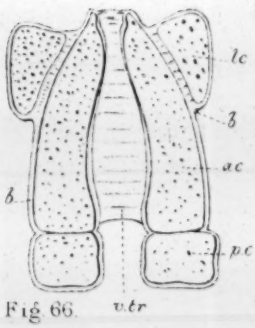
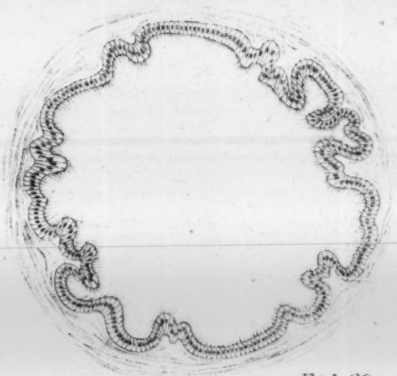


Fig. 66.


Fig. 69.

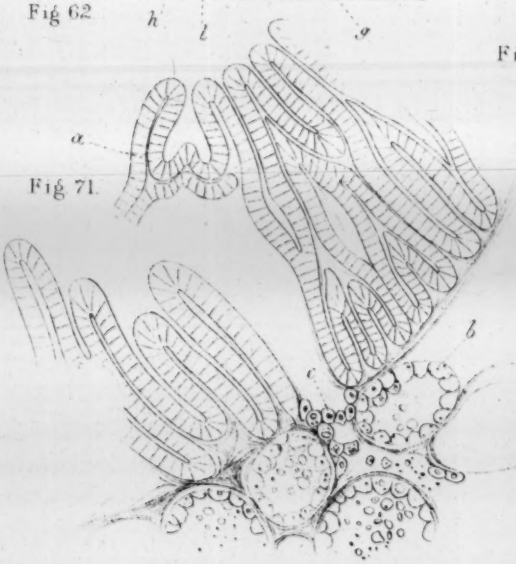


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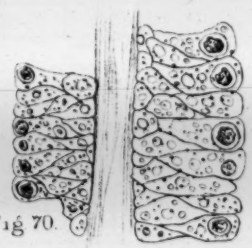

Fig. 70.


Fig. 72.

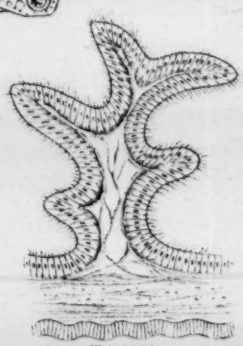
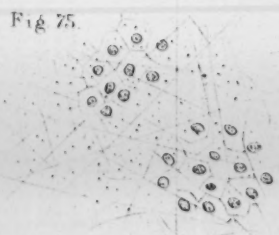

Fig. 73.


Fig. 74.


Fig. 75.

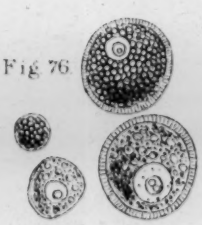
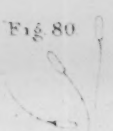

Fig. 76.


Fig. 77.


Fig. 78.


Fig. 79.


Fig. 80.

XXXIV.—*Detached Theorems on Circulants.* By Thomas Muir, LL.D.

(Read 4th May 1885.)

1. *If in a circulant the places* (r, s) *and* (p, q), *owing to the cyclical permutation, be occupied by the same element, then the complementary minor of this element in its first place is to its complementary minor in the second as* $(-1)^{r+s} : (-1)^{p+q}$.

To prove that the complementaries are as $(-1)^{r+s} : (-1)^{p+q}$ is the same as to prove that the cofactors are identical. And as the cofactor of an element of a determinant is not altered by the transposition of rows and columns provided the determinant itself is not thereby altered, it is evident that all we have to show is that the element in the place (r, s) may by transposition of rows and columns be made to take the place (p, q), and the determinant remain in outward form the same as before. Now it is a known property of the circulant that this can be done by first bringing the element in the place (r, s) into the pth row by cyclical transposition of rows, and thereafter making an exact similar set of transpositions of columns. Thus the theorem is established.

2. *If* a, b, c, ... *be the elements of the first row of a circulant, say of the fifth order, and* A, $-$B, C, $-$, ... *their complementaries, then the circulant is equal to*

$$(a+\omega b+\omega^2 c+\omega^3 d+\omega^4 e)(\mathrm{A}+\omega^4\mathrm{B}+\omega^3\mathrm{C}+\omega^2\mathrm{D}+\omega\mathrm{E})$$

where ω *is any fifth root of unity.*

Multiplying the circulant

$$\begin{vmatrix} a & b & c & d & e \\ e & a & b & c & d \\ d & e & a & b & c \\ c & d & e & a & b \\ b & c & d & e & a \end{vmatrix}, \quad \text{or} \quad \mathrm{C}\,(a\,b\,c\,d\,e),$$

by 1 in the form

$$\begin{vmatrix} 1 & \omega & \omega^2 & \omega^3 & \omega^4 \\ & 1 & & & \\ & & 1 & & \\ & & & 1 & \\ & & & & 1 \end{vmatrix}$$

we have

$$\mathrm{C}(a\ b\ c\ d\ e)=\begin{vmatrix} a+\omega b+\omega^2 c+\omega^3 d+\omega e & b & c & d & e \\ e+\omega a+\omega^2 b+\omega^3 c+\omega^4 d & a & b & c & d \\ d+\omega e+\omega a+\omega^3 b+\omega^4 c & e & a & b & c \\ c+\omega d+\omega^2 e+\omega^3 a+\omega^4 b & d & e & a & b \\ b+\omega c+\omega^2 d+\omega^3 e+\omega^4 a & c & d & e & a \end{vmatrix},$$

$$=(a+\omega b+\omega^2 c+\omega^3 d+\omega^4 e)\begin{vmatrix} 1 & b & c & d & e \\ \omega & a & b & c & d \\ \omega^2 & e & a & b & c \\ \omega^3 & d & e & a & b \\ \omega^4 & c & d & e & a \end{vmatrix},$$

$$=(a+\omega b+\omega^2 c+\omega^3 d+\omega^4 e)(\mathrm{A}+\omega\mathrm{E}+\omega^2\mathrm{D}+\omega^3\mathrm{C}+\omega^4\mathrm{B}),$$

as was to be shown.

3. *If the linear factors of a circulant, say of the fifth order, be* α, β, γ, . . ., *and the complementary minors of the elements of the first row be* A, −B, C, − . . ., *then*

$$\mathrm{C}(\alpha\beta\gamma\delta,\ \alpha\beta\gamma\epsilon,\ \alpha\beta\delta\epsilon,\ \alpha\gamma\delta\epsilon,\ \beta\gamma\delta\epsilon)=5^5\mathrm{ABCDE}.$$

Let us denote by ρ one of the *imaginary* fifth roots of unity, the other roots being ρ^2, ρ^3, ρ^4, 1, and we have from § 2

$$\begin{aligned}\mathrm{C}(a,b,c,d,e)&=(a+\omega\ b+\omega^2 c+\omega^3 d+\omega^4 e)\ (\mathrm{A}+\omega\ \mathrm{E}+\omega^2\mathrm{D}+\omega^3\mathrm{C}+\omega^4\mathrm{B}),\\ &=(a+\omega^2 b+\omega^4 c+\omega\ d+\omega^3 e)\ (\mathrm{A}+\omega^2\mathrm{E}+\omega^4\mathrm{D}+\omega\ \mathrm{C}+\omega^3\mathrm{B}),\\ &=(a+\omega^3 b+\omega\ c+\omega^4 d+\omega^2 e)\ (\mathrm{A}+\omega^3\mathrm{E}+\omega\ \mathrm{D}+\omega^4\mathrm{C}+\omega^2\mathrm{B}),\\ &=(a+\omega^4 b+\omega^3 c+\omega^2 d+\omega\ e)\ (\mathrm{A}+\omega^4\mathrm{E}+\omega^3\mathrm{D}+\omega^2\mathrm{C}+\omega\ \mathrm{B}),\\ &=(a+\ \ b+\ \ c+\ \ d+\ \ e)\ (\mathrm{A}+\ \ \mathrm{E}+\ \ \mathrm{D}+\ \ \mathrm{C}+\ \ \mathrm{B}).\end{aligned}$$

From these by division there result

$$\left.\begin{aligned}&\mathrm{A}+\omega\ \mathrm{E}+\omega^2\mathrm{D}+\omega^3\mathrm{C}+\omega^4\mathrm{B}=\beta\gamma\delta\epsilon\\ &\mathrm{A}+\omega^2\mathrm{E}+\omega^4\mathrm{D}+\omega\ \mathrm{C}+\omega^3\mathrm{B}=\gamma\delta\epsilon\alpha\\ &\mathrm{A}+\omega^3\mathrm{E}+\omega^1\mathrm{D}+\omega^4\mathrm{C}+\omega^2\mathrm{B}=\delta\epsilon\alpha\beta\\ &\mathrm{A}+\omega^4\mathrm{E}+\omega^3\mathrm{D}+\omega^2\mathrm{C}+\omega^1\mathrm{B}=\epsilon\alpha\beta\gamma\\ &\mathrm{A}+\ \ \mathrm{E}+\ \ \mathrm{D}+\ \ \mathrm{C}+\ \ \mathrm{B}=\alpha\beta\gamma\delta\end{aligned}\right\}.$$

Calling the right-hand members here a', b', c', d', e', we see readily that

$$\left.\begin{aligned}a'+\ \ b'+\ \ c'+\ \ d'+e'&=5\mathrm{A}\\ \omega\ a'+\omega^2 b'+\omega^3 c'+\omega^4 d'+e'&=5\mathrm{B}\\ \omega a'+\omega^4 b'+\omega^1 c'+\omega^3 d'+e'&=5\mathrm{C}\\ \omega^3 a'+\omega^1 b'+\omega^4 c'+\omega^2 d'+e'&=5\mathrm{D}\\ \omega^4 a'+\omega^3 b'+\omega^2 c'+\omega\ d'+e'&=5\mathrm{E}\end{aligned}\right\},$$

and therefore by multiplication

$$C(a', b', c', d', e') = 5^5 ABCDE,$$

as was to be proved.

4. *If the elements of the first row of a circulant of the* n*th order be multiplied by* $\omega^n, \omega^{n-1}, \ldots, \omega$ *respectively, the elements of the second row by* $\omega^{n-1}, \omega^{n-2}, \ldots, \omega, \omega^n$ *respectively, the elements of the third row by* $\omega^{n-2}, \omega^{n-3}, \ldots, \omega, \omega^n, \omega^{n-1}$ *respectively, and so on, where* ω *is any* n*th root of unity, the circulant is unaltered in value.*

If we take the circulant as thus changed outwardly, and multiply all the elements of the second row by ω, all the elements of the third row by ω^2, and so forth, the elements of the first column will have ω^n for a common factor, the elements of the second column will have ω^{n-1}, the elements of the third column ω^{n-2}, and so on. We thus can strike out of the columns the very factors we introduced into the rows (with the immaterial addition of ω^n, *i.e.*, 1), and leave the circulant as it originally stood free of ω:—which proves the theorem.

5. If we take two skew circulants, of the 5th order say, $C'(a_1, \ldots, a_5)$, $C'(b_1, \ldots, b_5)$ and write the first in the form

$$\begin{vmatrix} a_1 & a_2 & a_3 & a_4 & a_5 \\ -a_5 & a_1 & a_2 & a_3 & a_4 \\ -a_4 & -a_5 & a_1 & a_2 & a_3 \\ -a_3 & -a_4 & -a_5 & a_1 & a_2 \\ -a_2 & -a_3 & -a_4 & -a_5 & a_1 \end{vmatrix},$$

and the other with its rows in reversed order, then the determinant whose every element is the sum of the corresponding elements in these two determinants, that is to say, the determinant

$$\begin{vmatrix} a_1-b_2 & a_2-b_3 & a_3-b_4 & a_4-b_5 & a_5-b_1 \\ -a_5-b_3 & a_1-b_4 & a_2-b_5 & a_3+b_1 & a_4+b_2 \\ -a_4-b_4 & -a_5-b_5 & a_1+b_1 & a_2+b_2 & a_3+b_3 \\ -a_3-b_5 & -a_4+b_1 & -a_3+b_2 & a_1+b_3 & a_2+b_4 \\ -a_2+b_1 & -a_3+b_2 & -a_4+b_3 & -a_5+b_4 & a_1+b_5 \end{vmatrix},$$

has for a factor

$$\begin{matrix} (a_1+\omega^{-1}a_2+\omega^{-2}a_3+\omega^{-3}a_4+\omega^{-4}a_5) & (a_1+\omega a_2+\omega^2 a_3+\omega^3 a_4+\omega^4 a_5) \\ -(b_1+\omega^{-1}b_2+\omega^{-2}b_3+\omega^{-3}b_4+\omega^{-4}b_5) & (b_1+\omega b_2+\omega^2 b_3+\omega^3 b_4+\omega^4 b_5) \end{matrix}$$

where ω is an imaginary fifth root of -1, the linear factor which remains being

$$a_1-a_2+a_3-a_4+a_5+b_1-b_2+b_3-b_4+b_5.$$

This is equivalent to saying that the determinant is equal to

$$\begin{aligned}&\left[\Sigma a_1^2+2\cos 36^\circ\,(a_1a_2+a_2a_3+a_3a_4+a_4a_5-a_5a_1)+2\cos 72^\circ\,(a_1a_3+a_2a_4+a_3a_5-a_4a_1-a_3a_2\right.\\&\left.-\Sigma b_1^2-2\cos 36^\circ\,(b_1b_2+b_2b_3+b_3b_4+b_4b_5-b_5b_1)-2\cos 72^\circ\,(b_1b_3+b_2b_4+b_3b_5-b_4b_1-b_5b_2)\right]\times\\&\left[\Sigma a_1^2-2\cos 72^\circ\,(a_1a_2+a_2a_3+a_3a_4+a_4a_5-a_5a_1)-2\cos 36^\circ\,(a_1a_3+a_2a_4+a_3a_5-a_4a_1-a_3a_2\right.\\&\left.-\Sigma b_1^2+2\cos 72^\circ\,(b_1b_2+b_2b_3+b_3b_4+b_4b_5-b_5b_1)+2\cos 36^\circ\,(b_1b_3+b_2b_4+b_3b_5-b_4b_1-b_5b_1)\right]\times\\&\left[a_2-a_2+a_3-a_4+a_5+b_1-b_2+b_3-b_4+b_5\right],\end{aligned}$$

where the law of signs in

$$a_1a_2+a_2a_3+a_3a_4+a_4a_5-a_5a_1 \quad \text{and} \quad a_1a_3+a_2a_4+a_3a_5-a_4a_1-a_3a_2$$

is made clear by noting that each expression is got from two rows of $C'(a_1, a_2, a_3, a_4, a_5)$, the former being $(a_1, a_2, a_3, a_4, a_5, \&-a_5, a_1, a_2, a_3, a_4)$ and the latter $(-a_2, -a_3, -a_4, -a_5, a_1\&-a_3, -a_4, a_5, -a_1, a_2)$.

This theorem is established exactly as its analogue in ordinary circulants. (See *Messenger of Math.*, xi. pp. 105–108.)

6. One of the hardest problems connected with circulants is the finding of the final expansion of the circulant of the nth order. Anything that has been done towards a solution will be found in the following papers: GLAISHER, *Quart. Journ. of Math.*, xv. p. 354, xvi. p. 33; MUIR, *Quart. Journ. of Math.*, xviii. pp. 176, 177; FORSYTH, *Mess. of Math.*, xiv. pp. 43–46.; MUIR, *Mess. of Math.*, xiv. pp. 169–175.

One plan which occurred to me of determining the law of the coefficients was to try to hit upon a determinant of some more general form than the circulant and having an easier law of formation for its final expansion, and then to specialise. The determinant which seemed to offer fairest promise is exemplified by

$$\begin{vmatrix} a\alpha & b\beta & c\gamma & d\delta & e\epsilon \\ e\beta & a\gamma & b\delta & c\epsilon & da \\ d\gamma & e\delta & a\epsilon & ba & c\beta \\ c\delta & d\epsilon & ea & a\beta & b\gamma \\ b\epsilon & ca & d\beta & e\gamma & a\delta \end{vmatrix}.$$

It evidently degenerates into the circulant $C(a, b, c, d, e)$ when $\alpha=\beta=\gamma=\delta=\epsilon=1$, and, what is of importance, the letters $\alpha, \beta, \gamma, \delta, \epsilon$ are themselves introduced in cyclical fashion, the determinant, in fact, degenerating into the circulant $C(\alpha, \beta, \gamma, \delta, \epsilon)$ when $a=b=c=d=e=1$. This determinant I find equal to

$$\begin{aligned}&(a^5+b^5+c^5+d^5+e^5)a\beta\gamma\delta\epsilon\\&-(a^3be+b^3ca+c^3db+d^3ec+e^3ad)\,(a^3\gamma\delta+\beta^3\delta\epsilon+\gamma^3\epsilon a+\delta^3a\beta+\epsilon^3\beta\gamma)\\&-(a^3cd+b^3de+c^3ea+d^3ab+e^3bc)\,(a^3\beta\epsilon+\beta^3\gamma a+\gamma^3\delta\beta+\delta^3\epsilon\gamma+\epsilon^3a\delta)\\&+(a^2b^2d+b^2c^2e+c^2d^2a+d^2e^2b+e^2a^2c)\,(a^2\beta\gamma^2+\beta^2\gamma\delta^2+\gamma^2\delta\epsilon^2+\delta^2\epsilon a^2+\epsilon^2a\beta^2)\\&+(a^2bc^2+b^2cd^2+c^2de^2+d^2ea^2+e^2ab^2)\,(a^2\beta^2\delta+\beta^2\gamma^2\epsilon+\gamma^2\delta^2a+\delta^2\epsilon^2\beta+\epsilon^2a^2\gamma)\\&-10abcdea\beta\gamma\delta\epsilon,\end{aligned}$$

which, using $\overset{\circ}{\Sigma}$ for *cyclic sum*, we may write in the form

$$\overset{\circ}{\Sigma}a^5.\,a\beta\gamma\delta\epsilon - \overset{\circ}{\Sigma}a^3be\overset{\circ}{\Sigma}a^3\gamma\delta - \overset{\circ}{\Sigma}a^3cd\overset{\circ}{\Sigma}a^3\beta\epsilon + \overset{\circ}{\Sigma}a^2b^2d\overset{\circ}{\Sigma}a^2\beta\gamma^2 + \overset{\circ}{\Sigma}a^2bc^2\overset{\circ}{\Sigma}a^2\beta^2\delta - 10\,abcdea\beta\gamma\delta\epsilon\,.$$

Putting $a=\beta=\gamma=\delta=\epsilon=1$, we obtain

$$\left.\begin{aligned} C(a,\,b,\,c,\,d,\,e) = \overset{\circ}{\Sigma}a^5 - 5\overset{\circ}{\Sigma}a^3bc - 5\overset{\circ}{\Sigma}a^3cd + 5\overset{\circ}{\Sigma}a^2b^2d + 5\overset{\circ}{\Sigma}a^2bc^2 \\ - 10\,abcdea\beta\gamma\delta\epsilon\,, \end{aligned}\right\}$$

and it is seen how the coefficients, -5, -5, 5, 5 originate. Unfortunately the general determinant still contains a set of unsifted terms, viz., $10\,abcdea\beta\gamma\delta\epsilon$, which are got, curiously enough, from the elements by a series of knight's moves. Though therefore the discussion of the problem may be advanced in this way, the full solution is not yet in sight.

XXXV.—*On the Hessian.* By Professor CHRYSTAL.

(Read 18th May 1885.)

1. Let

$$U \equiv u_0 z^n + u_1 z^{n-1} + u_2 z^{n-2} + \ldots = 0$$

be the equation to an algebraical curve of the nth degree, the co-ordinates of any point on which in a system of linear co-ordinates are (x, y, z), $u_0, u_1, u_2 \ldots$ being homogeneous functions of x and y of degrees indicated by the attached suffixes; then

$$H \equiv U_{xx} U_{yy} U_{zz} + 2U_{yz} U_{zx} U_{xy} - U_{xx} U_{yz}^2 - U_{yy} U_{zx}^2 - U_{zz} U_{xy}^2 = 0$$

is the equation to its Hessian, which is a curve of the $3(n-2)$th degree.

Every one of the $3n(n-2)$ points of intersection of H and U is a point of inflexion on U if it be not a multiple point on U. In this last case the intersection may or may not be a point of inflexion on some one of the branches of U; but in any case where H passes through a multiple point the total number $3n(n-2)$ of inflexions suffers a reduction. It is therefore a problem of great geometrical interest to calculate the number of the intersections of H and U which are absorbed at a multiple point on the latter. This problem has never been solved directly in any but a few simple cases. It has been shown, for example, that at an ordinary double point on U, H has also a double point the tangents at which are the same as the tangents at the double point on U, and that such a point absorbs $2 \times 2 + 2 = 6$ of the intersections $\widehat{HU}$; also that a multiple point of order k, all of whose tangents are distinct, is a multiple point of order $3k-4$ on H, k of whose tangents are tangents to U, and that such a point absorbs $k(3k-4) + k = 6 \times \frac{1}{2}k(k-1)$ intersections,—in other words, has the same effect as the $\frac{1}{2}k(k-1)$ ordinary double points to which it may be regarded as equivalent. It has also been shown that a point which is a cusp of the ordinary kind on U is a triple point on H, two of whose tangents coincide with the cuspidal tangent of U; this cusp counting for $2 \times 3 + 2 = 8$ among $\widehat{HU}$. Finally, CAYLEY has laid down that every singularity of an algebraical curve can be regarded, for our present purpose, as equivalent to a certain number δ of ordinary double points, and a certain number κ of ordinary cusps. But the proofs which have been given of this theory by NÖTHER, ZEUTHEN, STOLZ, HENRY SMITH, and the methods given for ascertaining the indices δ and κ, are of an indirect nature, and it has been doubted whether any proof of this theory can be given by methods appropriate to co-ordinate geometry.

The direct calculation of the reduction is therefore a general problem, whose interest is quite equal to its difficulty. With a view to clear the way for a general solution (if such be attainable) I have worked out a number of cases, some quite special, others of a more general character, and propose to communicate the solutions to the Society in the following paper.

2. In its ultimate stage the problem reduces to the following:—

To determine the number $\widehat{UV}$ of the intersections of two algebraical curves $U=0$, $V=0$, which coincide with a common point which is multiple on one or both.

Let us suppose that the common point is a multiple point of order k on U and of order κ on V.

So long as no one of the k tangents of U coincides with any one of the κ tangents of V, there is no difficulty; the number of intersections absorbed at the common point is $k\kappa$.

But let us suppose that l of the k tangents and λ of the κ tangents coincide with $x=0$, then we have

$$U \equiv x^l u_{k-l} + u_{k+1} + \ldots\ldots$$
$$V = x^\lambda u_{\kappa-\lambda} + u_{\kappa+1} + \ldots\ldots$$

or, what is still worse, that $x=0$ is a multiple inflexional or undulatory tangent, so that

$$U \equiv x^l u_{k-l} + x^m u_{k+1-m} + x^n u_{k+2-n} + \ldots\ldots$$
$$V \equiv x^\lambda v_{\kappa-\lambda} + x^\mu v_{\kappa+1-\lambda} + x^\nu v_{\kappa+2-\nu} + \ldots\ldots$$

and the problem becomes one of some difficulty.

In many cases the solution may be obtained by the following process:—

Ex. 1.

Let us suppose

$$U \equiv x^3 u_5 + u_{10}$$
$$V \equiv x^4 v_1 + v_7.$$

$$\text{Let } K \equiv x v_1 U - u_5 V \equiv x v_1 u_{10} - u_5 v_7 \equiv u_{12},$$

say, where u_{12} does not contain x as a factor. Then, since K passes through all the intersections of U and V, taking $\widehat{VU}$ to denote the number of those intersections which coincide with $x=0$ $y=0$ we have, since

$$\left.\begin{matrix} U=0 \\ K=0 \end{matrix}\right\} \text{gives } u_5 V = 0 \text{ and } \therefore \left.\begin{matrix} U=0 \\ u_5 V=0 \end{matrix}\right\},$$

$$\widehat{UK} = \widehat{UV} + \widehat{Uu_5}$$

$$\textit{i.e.,}\ \widehat{Uu_{12}} = \widehat{UV} + \widehat{Uu_5},$$

whence

$$\widehat{UV} = \widehat{Uu_{12}} - \widehat{Uu_5}.$$

Now, provided none of the linear factors of u_{12} occur in xu_5, and none of those of u_5 in u_{10} we have

$$\widehat{Uu_{12}} = 8 \times 12$$
$$\widehat{Uu_5} = \widehat{u_{10}u_5} = 10 \times 5$$

whence finally $\widehat{UV} = 96 - 50 = 46.$

We may consider the more general case.

Ex. 2.

$$U \quad x^m u_{k-m} + u_{k+r} \qquad m > \mu$$
$$V \equiv x^\mu v_{\kappa-\mu} + v_{\kappa+\rho} \qquad r < \rho,$$

of which Ex. 1 is a particular case; it may be shown by the above method that

$$\widehat{UV} = k\kappa + r\mu,$$

This obviously agrees with the result of Ex. 1, and also with the following.

Ex. 3.

$$U \equiv x^2 - y^3$$
$$V \equiv x - y^3$$

$$\widehat{UV} = 2 \times 1 + 1 \times 1 = 3.$$

The figure corresponding to this case is

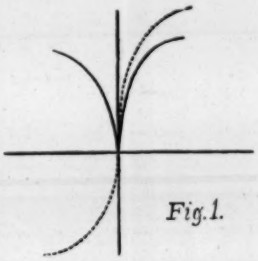


Fig. 1.

which may be looked upon as the limiting case of

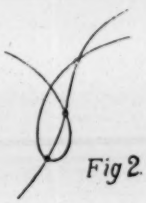


Fig 2.

If in Ex. 2 $r > \rho$ the application of the above method is not so simple, and the result is not in all cases the same as will be shown directly.

For the sake of comparison with the results of another process shortly to be indicated, I work out two more examples by the present method.

Ex. 4.

$$U \equiv x^3 u_5 + x^2 u_7 + u_{10}$$
$$V \equiv x^4 v_1 + x^3 v_3 + v_7,$$

we have

$$K \equiv xv_1 U - u_5 V \equiv x^3(v_1 u_7 - u_5 v_3) + xv_1 u_{10} - u_5 v_7$$
$$\equiv x^3 u_8 + u_{12} \text{ say}$$
$$L \equiv u_5 K - u_8 U \equiv u_{17} + u_{18} \text{ say}$$
$$\therefore 8 \times 17 = \widehat{UL} = \widehat{UK} + \widehat{Uu_5}$$
$$= \widehat{UV} + \widehat{Uu_5} + \widehat{Uu_5}$$
$$= \widehat{UV} + 2\widehat{(x^2 u_7)u_5}$$
$$136 = \widehat{UV} + 90$$
$$\widehat{UV} = 46$$

Ex. 5.

$$\begin{aligned}
&\mathrm{U}\equiv x^3u_5 + xu_8 + u_{10}\\
&\mathrm{V}\equiv x^4v_1 + x^3v_3 + v_7\\
&\mathrm{K}\equiv xv_1\mathrm{U} - u_5\mathrm{V} \equiv x^2u_9 + u_{12}\\
&\mathrm{L}\equiv xu_5\mathrm{K} - u_9\mathrm{U} \equiv xu_{17} + u_{19}\\
&\mathrm{M}\equiv xu_9\mathrm{L} - u_{17}\mathrm{K} \equiv u_{29}\\
11\times 29 = \widehat{\mathrm{MK}} &= \widehat{\mathrm{KL}} + \widehat{x\mathrm{K}} + \widehat{u_9\mathrm{K}}\\
&= \widehat{\mathrm{KL}} + \widehat{xu_{12}} + \widehat{u_9u_{12}}\\
&= \widehat{\mathrm{KU}} + \widehat{\mathrm{K}u_9} + \widehat{xu_{12}} + \widehat{u_9u_{12}}\\
&= \widehat{\mathrm{KU}} + \widehat{xu_{12}} + 2\widehat{u_9u_{12}}\\
&= \widehat{\mathrm{UV}} + \widehat{u_5\mathrm{U}} + \text{ \&c.}\\
&= \widehat{\mathrm{UV}} + \widehat{xu_5} + \widehat{u_5u_8} + 2\widehat{u_9u_{12}} + \widehat{xu_{12}}\\
\widehat{\mathrm{UV}} &= 319 - 5 - 40 - 216 - 12 = 46.
\end{aligned}$$

3. The process just exemplified is tedious to apply and capricious in its action, and affords, besides, no indication of generality. It clearly contains redundant steps, for in the three examples (1) (4) (5) the same final result, viz., $\widehat{\mathrm{UV}}=46$, is obtained by extremely different developments. Yet it is obvious, *a priori*, that the same final result ought to be arrived at in all these cases, since the additional terms which appear in U and V in examples (4) and (5) are such that they do not affect the forms of U and V at the point $x=0$ $y=0$, which alone can be supposed to affect $\widehat{\mathrm{UV}}$.

It is at once suggested, therefore, that the problem will be simplified by substituting for U and V the approximations to their branches at the origin determined by the rule of NEWTON and CRAMER. In this way we can in general reduce the problem to a series of others, of which the following is a type.

To determine the number of intersections of

$$\mathrm{U}\equiv x^m - y^n = 0 \ldots . (1) \quad \text{and} \quad \mathrm{V}\equiv x^\mu - y^\nu = 0 \ldots . (2)$$

at the point $x=0$ $y=0$.

Since imaginary branches must be considered as well as real branches, it may be well to give a rigorous proof of the solution in this simple case.

If $a_1a_2 \ldots . a_n$ be the n roots of $+1$, the n values of y given by $y^n=x^m$ are

$$a_1x^{\frac{m}{n}},\ a_2x^{\frac{m}{n}} \ldots . a_nx^{\frac{m}{n}}.$$

The eliminant of the two equations (1) and (2) with respect to y is therefore

$$\left\{x^\mu - \left(a_1x^{\frac{m}{n}}\right)^\nu\right\}\left\{x^\mu - \left(a_2x^{\frac{m}{n}}\right)^\nu\right\} \ldots . \left\{x^\mu - \left(a_nx^{\frac{m}{n}}\right)^\nu\right\} = 0,$$

that is

$$\left(x^{\frac{m\nu}{n}}\right)^n \left\{x^{\frac{\mu n - m\nu}{n}} - a_1^\nu\right\}\left\{x^{\frac{\mu n - m\nu}{n}} - a_2^\nu\right\} \ldots . \left\{x^{\frac{\mu n - m\nu}{n}} - a_n^\nu\right\} = 0,$$

Now, if g be the G.C.M. of n and ν, and $n=gn'$, $\nu=g\nu'$, then the series $a_1^\nu, a_2^\nu, \ldots . a_n^\nu$ simply consists of the roots of $x^{n'}-1=0$ repeated g times. Hence the equation last written reduces to

$$x^{g m\nu'}(x^{\mu n' - m\nu'} - 1)^g = 0, \qquad \text{that is } (x^{\mu n'} - x^{m\nu'})^g = 0 \ldots . (3),$$

where from the nature of the process employed we are sure that there is no redundant factor.

Now $x^{\mu n}$ or $x^{m\nu}$ is a factor in (3) according as $\mu n <$ or $> m\nu$, *i.e.*, the number of zero roots of (3) is the least of the two numbers μn $m\nu$.

Hence denoting for shortness the least of the two μn $m\nu$ by $l(\mu n, m\nu)$, we have the following simple theorem.

The number of intersections of $x^m - y^n = 0$ and $x^\mu - y^\nu = 0$ at the point $x=0$ $y=0$, is

$$l(\mu n, m\nu).$$

4. By means of the NEWTON-CRAMER rule we can, as far as points near $x=0$ $y=0$ are concerned, replace U and V by

$$\mathrm{U}' \equiv (x^{m_1} - \mathrm{A}_1 y^{n_1})(x - \mathrm{A}_2 y^{n_2}) \ldots .$$
$$\mathrm{V}' = (x^{\mu_1} - \mathrm{B}_1 y^{\nu_1})(x^{\mu_2} - \mathrm{B}_2 y^{\nu_2}) \ldots ,$$

where the factors in U′ will in general be all different, those in V′ all different, and no factor common to U′ and V′.

In this case we can at once find the number $\widehat{\mathrm{UV}}$. We have, in fact,

$$\widehat{\mathrm{UV}} = \widehat{\mathrm{U}'\mathrm{V}'} = l(m_1 \nu_1, n_1 \mu_1) + l(m_1 \nu_2, n_1 \mu_2) + \ldots .$$
$$+ l(m_2 \nu_1, n_2 \mu_1) + l(m_2 \nu_2, n_2 \mu_2) + \ldots .$$
$$+ \ldots .$$

This result still holds when factors are repeated in U′ or in V′; but when there are factors common to U′ and V′ there is a modification, as will be shown presently.

5. Before proceeding farther, let us apply the above principles to one or two examples.

Ex. 1.
$$\mathrm{U} \equiv x^3 u_5 + x^2 u_7 + u_{10} = 0$$
$$\mathrm{V} \quad x^4 v_1 + x^3 v_3 + v_7 = 0.$$

The NEWTON-CRAMER diagrams for U and V show at once that (omitting constant coefficients as irrelevant to the issue) we may write

$$\mathrm{U} \equiv u_5(x^3 + y^5) \qquad \mathrm{V} \equiv v_1(x^4 + y^6);$$
$$\therefore \widehat{\mathrm{UV}} = 5\times 1 + 5\times 4 + 3\times 1 + 3\times 6 = 46,$$

the same result as before.

Ex. 2.
$$\mathrm{U} \equiv x^3 u_5 + x u_8 + u_{10}$$
$$\mathrm{V} \equiv x^4 v_1 + x^3 v_3 + v_7.$$

Here it is easily shown that we may write

$$\mathrm{U} \equiv u_5(x^2 + y^3)(x + y^2)$$
$$\mathrm{V} \equiv v_1(x^4 + y^6);$$
$$\therefore \widehat{\mathrm{UV}} = 5\times 1 + 5\times 4 + 2\times 1 + 2\times 6 + 1\times 1 + 1\times 6 = 46.$$

Ex. 3.
$$\mathrm{U} \equiv x^m u_{k-m} + u_{k-r}$$
$$\mathrm{V} - x^\mu v_{\kappa-\mu} + v_{\kappa+\rho}.$$

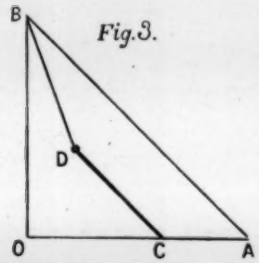


Fig. 3.

The diagrams here are both of the same character; that for U, for example, is figure 3, where AB and CD are parallel and each full of terms; the co-ordinates of D are $(m, k-m)$; and $OA=k+r$, $OC=k$. The two lines CD and BD give approxmations at $x=0$ $y=0$.

We may therefore write

$$U \equiv u_{k-m}(x^m+y^{r+m}), \qquad V \equiv v_{\kappa-\mu}(x^\mu+y^{\rho+\mu}).$$

Hence

$$\begin{aligned}\widehat{UV} &= (k-m)\kappa+m(\kappa-\mu)+l\{(\rho+\mu)m\,,(r+m)\mu\}\\ &= k\kappa-m\mu+m\mu+l(\rho m\,,r\mu)\\ &= k\kappa+l(\rho m\,,r\mu)\\ \text{i.e.,} &= k\kappa+\rho m \text{ or } =k\kappa+r\mu\,,\end{aligned}$$

according as $\rho m < \text{or} > r\mu$.

This result includes that of Ex. 2 in § 2 as a particular case.

Ex. 4. To illustrate the particular case of Ex. 3, where $m\rho<\mu r$, consider

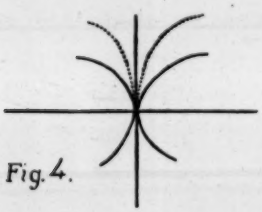
$$U\equiv x^2-y^4 \qquad V\equiv x^2-y^3$$

Here

$$\begin{aligned}&m=2,\ k=2,\ r=2,\\ &\mu=2,\ \kappa=2,\ \rho=1;\\ &m\rho=2,\ \mu r=4.\end{aligned}$$

$$\widehat{UV}=2\times2+2=6.$$

The corresponding figure is


Fig. 4.

which may, in fact, be considered as the limiting case of

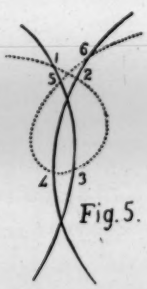


Fig. 5.

BRITISH
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(To be continued in another Communication.)

APPENDIX.

TRANSACTIONS

OF THE

ROYAL SOCIETY OF EDINBURGH.

1884-85.

VOL. XXXII. PART IV. 5 s

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LIST OF MEMBERS.

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ALPHABETICAL LIST OF ORDINARY FELLOWS,

AND LIST OF HONORARY FELLOWS.

At November 1886.

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OF

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NOVEMBER 1886.

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ALPHABETICAL LIST

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CORRECTED TO NOVEMBER 1886.

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K. ,, ,, ,, Keith Medal.
N. ,, ,, ,, Neill Medal.
P. ,, ,, ,, contributed one or more Papers to the TRANSACTIONS.

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1883		* Barclay, G. W. W., M.A., 40 Princes Street
1882		Barnes, Henry, M.D., M.R.C.S., 6 Portland Square, Carlisle
1874		Barrett, William F., M.R.I.A., Professor of Physics, Royal College of Science, Dublin
1878		Bateman, John Frederic La Trobe, Memb. Inst. C.E., F.R.S., F.G.S., F.R.G.S., 16 Great George Street, Westminster
1857		Batten, Edmund Chisholm, of Aigas, M.A., 16 Pelham Crescent, South Kensington, London
1880		* Bayly, General John, C.B., R.E., Ardincaple Castle, Helensburgh, Dumbartonshire
1882	P.	Beddard, Frank E., M.A. Oxon, Prosector to the Zoological Society of London, 9 Cleveland Terrace, Hyde Park, London, W.
1886		* Bell, A. Beatson, Chairman of Prison Commissioners, 130 George Street
1874		* Bell, Joseph, M.D., F.R.C.S.E., 2 Melville Crescent
1876		* Belcombe, Rev. F. E., 14 Merchiston Avenue
1875		Bernstein, Ludwik, M.D., Lismore, New South Wales
1881		* Berry, Walter, Danish Consul General, 11 Atholl Crescent
1880		* Birch, De Burgh, M.D., Professor of Physiology, University College, Leeds, 16 De Grey Terrace, Leeds
1884		* Black, James Tait, Gogar Park, Corstorphine
1884		* Black, Rev. John S., 6 Oxford Terrace
1850		Blackburn, Hugh, M.A., LL.D., Emeritus Professor of Mathematics in the University of Glasgow, Roshven, Ardgour
1863	P.	* Blackie, John S., Emeritus Prof. of Greek in the Univer. of Edin., 9 Douglas Crescent
1862		Blaikie, The Rev. W. Garden, M.A., D.D., LL.D., Professor of Apologetics and Pastoral Theology, New College, Edinburgh, 9 Palmerston Road
1878	P.	* Blyth, James, M.A., Professor of Natural Philosophy in Anderson's College, Glasgow
1884		Bond, Francis T., M.D., B.A., M.R.C.S., 1 Beaufort Buildings, Spa, Gloucester
1872		* Bottomley, J. Thomson, M.A., Lecturer on Natural Philosophy in the University of Glasgow
1869		* Bow, Robert Henry, C.E., 7 South Gray Street
1886		* Bower, Frederick O., Regius Professor of Botany in the University of Glasgow, 45 Kerrsland Terrace, Hillhead, Glasgow
1884		Bowman, Frederick Hungerford, D.Sc., F.R.A.S., F.C.S., F.G.S., F.L.S., West Mount, Halifax, Yorkshire
1871		* Boyd, Sir Thomas J., Chairman of the Scottish Fishery Board, 41 Moray Place
1873		* Boyd, William, M.A., Peterhead
1886		* Bramwell, Byrom, M.D., F.R.C.P.E., 23 Drumsheugh Gardens
1886		Brittle, John Richard, Memb. Inst. C.E., Vanbrugh Hill, Blackheath, Kent
1877		Broadrick, George, Memb. Inst. C.E., Elmfield Lodge, Doncaster
1864	K. B. P.	* Brown, Alex. Crum, M.D., D.Sc., F.R.C.P.E., F.R.S. (SECRETARY), Professor of Chemistry in the University of Edinburgh, 8 Belgrave Crescent
1881		* Brown, J. A. Harvie, of Quarter, Dunipace House, Larbert, Stirlingshire
1883		* Brown, J. Graham, M.D , C.M., F.R.C.P.E., 16 Ainslie Place
1885		* Brown, J. Macdonald, M.B., F.R.C.S.E., 6 Atholl Place
1861	P.	Brown, Rev. Thomas, 16 Carlton Street
1835		Brown, William, F.R.C.S.E., 25 Dublin Street
1870		Browne, Sir Jas. Crichton, M.D., LL.D., 7 Cumberland Terrace, Regent's Park, London, N.W.

Date of Election.		
1883		* Bruce, Alexander, M.A., M.B., M.R.C.P.E., 16 Alva Street
1878		Brunlees, Sir James, Memb. Inst. C.E., 5 Victoria Street, Westminster
1867		* Bryce, A. H., D.C.L., LL.D., 42 Moray Place
1869	B. P.	* Buchan, Alexander, M.A., Secretary to the Scottish Meteorological Society (CURATOR OF LIBRARY), 72 Northumberland Street 65
1870	P.	* Buchanan, John Young, M.A., 10 Moray Place
1882		* Buchanan, T. Ryburn, M.A., M.P. for the City of Edinburgh, 10 Moray Place
1883		* Butcher, S. H., M.A., LL.D., Professor of Greek in the University of Edinburgh, 27 Palmerston Place
1869		* Calderwood, Rev. H., LL.D., Professor of Moral Philosophy in the University of Edinburgh, Napier Road, Merchiston
1879		* Calderwood, John, F.I.C., Belmont Works, Battersea, London 70
1878		Campbell, John Archibald, M.D., Garland's Asylum, Carlisle
1874		Carrington, Benjamin, M.D., Eccles, Lancashire
1882		* Cay, W. Dyce, Memb. Inst. C.E., 107A Princes Street
1876		Cazenove, The Rev. John Gibson, M.A., D.D., 22 Alva Street, Chancellor of St Mary's Cathedral
1885		* Chambers, Robert, 10 Claremont Crescent 75
1866		* Chalmers, David, Redhall, Slateford
1874		* Chiene, John, M.D., F.R.C.S.E., Professor of Surgery in the University of Edinburgh, 26 Charlotte Square
1875		* Christie, John, 19 Buckingham Terrace
1872		Christie, Thomas B., M.D., F.R.C.P.E., Royal India Asylum, Ealing, London
1880	K. P.	* Chrystal, George, M.A., Professor of Mathematics in the University of Edinburgh, 5 Belgrave Crescent 80
1875		* Clark, Robert, 7 Learmonth Terrace
1886		* Clark, The Right Hon. Sir Thomas, Bart., Lord Provost of Edinburgh, 11 Melville Crescent
1863	P.	Cleghorn, Hugh F. C., of Stravithie, M.D., LL.D., F.L.S., St Andrews, United Service Club, 13 Queen Street
1875		* Clouston, T. S., M.D., F.R.C.P.E., Tipperlin House, Morningside
1882		* Coats, Sir Peter, of Auchendrane, President of the Glasgow and West of Scotland Horticultural Society, Auchendrane, Ayr 85
1886		Connan, Daniel M., M.A., Education Department, Cape of Good Hope
1872		* Constable, Archibald, 11 Thistle Street
1863		Cowan, Charles, of Westerlea, Murrayfield
1879		* Cox, Robert, of Gorgie, M.A., 34 Drumsheugh Gardens
1875		* Craig, William, M.D., F.R.C.S.E., 7 Bruntsfield Place 90
1886		* Croom, John Halliday, M.D., 25 Charlotte Square
1873		* Crawford, Donald, M.A., Advocate, M.P., 18 Melville Street
1878		* Cunningham, Daniel John, M.D., Professor of Anatomy in Trinity College, Dublin
1886		* Cunningham, David, Memb. Inst. C.E., Dundee
1877	P.	* Cunningham, George Miller, 2 Ainslie Place 95
1884		* Cunningham, J. T., B.A., 1 Walker Street
1871		* Cunynghame, R. J. Blair, M.D., 6 Walker Street
1841	P.	Dalmahoy, James, 9 Forres Street
1878		* Dalziel, John Grahame, 2 Melville Terrace, Pollokshields, Glasgow
1885		* Daniell, Alfred, M.A., LL.B., D.Sc., Advocate, 3 Great King Street 100
1867		* Davidson, David, Somerset Lodge, Wimbledon Common, Wimbledon

Date of Election.		
1848		Davidson, Henry, Muirhouse, Davidson's Mains
1884		Davy, Richard, M.B., F.R.C.S., Surgeon to the Westminster Hospital, 33 Welbeck Street, Cavendish Square, London, W.
1870		* Day, St John Vincent, C.E., 115 St Vincent Street, Glasgow, and 12 Rothesay Place, Edinburgh
1876		* Denny, Peter, Memb. Inst. C.E., Dumbarton 105
1879		* Denny, William, Memb. Inst. C.E., Bellfield, Dumbarton
1869	P.	* Dewar, James, M.A., F.R.S., Jacksonian Professor of Natural and Experimental Philosophy in the University of Cambridge, and Fullerian Professor of Chemistry at the Royal Institution of Great Britain, London
1869	P.	* Dickson, Alexander, M.D., Professor of Botany in the University of Edinburgh, 11 Royal Circus
1884		* Dickson, Charles Scott, Advocate, 59 Northumberland Street
1876	P.	* Dickson, J. D. Hamilton, M.A., Fellow and Tutor, St Peter's College, Cambridge 110
1869		* Dickson, William, 38 York Place
1863		* Dittmar, W., F.R.S., Professor of Chemistry, Anderson's College, Glasgow
1885		Dixon, J. M., Professor of English Literature in the University of Tokio, Japan
1881		* Dobbin, Leonard, Ph.D., 4 Oxford Street
1867	P.	* Donaldson, J., M.A., LL.D., Principal of the United College of St Salvador and St Leonard, St Andrews 115
1882		* Dott, D. B., Memb. Pharm. Soc., 24 Castle Street
1866		* Douglas, David, 22 Drummond Place
1878		Drew, Samuel, M.D., D.Sc.. Chapelton, near Sheffield
1880		* Drummond, Henry, F.G.S., Prof. of Natural History in the Free Church College, Glasgow
1860		Dudgeon, Patrick, of Cargen, Dumfries, 27 Glencairn Crescent 120
1863	P.	Duncan, J. Matthews, M.A., M.D., F.R.C.P.E., LL.D., F.R.S., 71 Brook Street, London
1870		* Duncan, John, M.D., F.R.C.P.E., F.R.C.S.E., 8 Ainslie Place
1876		* Duncan, James, of Benmore, Kilmun, 9 Mincing Lane, London, E.
1878		* Duncanson, J. J. Kirk, M.D., F.R.C.P.E., 22 Drumsheugh Gardens
1859		Duns, Rev. Professor, D.D., New College, Edinburgh, 14 Greenhill Place 125
1874		* Durham, William, Seaforth House, Portobello
1869		* Elder, George, Knock Castle, Wemyss Bay, Greenock
1885		* Elgar, Francis, LL.D., The Admiralty, London
1875		Elliot, Daniel G., New York
1880		* Elliot, T. Armstrong, M.A., Fettes College 130
1855		Etheridge, Robert, F.R.S., Assistant-Keeper of the Geological Department at the British Museum of Natural History, 14 Carlyle Square, Chelsea, London
1884		* Evans, William, F.F.A., 18A Morningside Park, Edinburgh
1863	P.	Everett, J. D., M.A., D.C.L., F.R.S., Professor of Natural Philosophy, Queen's College, Belfast
1879		* Ewart, James Cossar, M.D., F.R.C.S.E., Professor of Nat. Hist., University of Edinburgh, 3 Great Stuart Street
1878	P.	* Ewing, James Alfred, B.Sc., Professor of Engineering and Drawing in University College, Dundee 135
1875		Fairley, Thomas, Lecturer on Chemistry, 8 Newton Grove, Leeds
1866		* Falshaw, Sir James, Bart., Assoc. Inst. C.E., 14 Belgrave Crescent

Date of Election.		
1859		Fayrer, Sir Joseph, K.C.S.I., M.D., F.R.C.P.L., F.R.C.S.L. and E., LL.D., F.R.S., Honorary Physician to the Queen, 53 Wimpole Street, London, W.
1883		* Felkin, Robert W., M.D., F.R.G.S., Fellow of the Anthropological Society of Berlin, 20 Alva Street, Edinburgh
1868		* Ferguson, Robert M., Ph.D., 12 Moray Place 140
1874		* Ferguson, William, of Kinmundy, F.L.S., F.G.S., Deputy-Lieutenant of Aberdeenshire, 21 Manor Place, Edinburgh, and Kinmundy House, near Mintlaw
1886		Field, C. Leopold, F.C.S., Upper Marsh, Lambeth, London
1852		Fleming, Andrew, M.D., Deputy Surgeon-General, 3 Napier Road
1876		* Fleming, J. S., 16 Grosvenor Crescent
1880		* Flint, Robert, D.D., Corresponding Member of the Institute of France, Professor of Divinity in the University of Edinburgh, Johnstone Lodge (Vice-President), 54 Craigmillar Park 145
1872		* Forbes, G., Professor, M.A., F.R.A.S., M.S.T.E. and E., 34 Great George Street, Westminster
1859		Forlong, Major-Gen. J. G., F.R.G.S., R.A.S., Assoc. C.E., &c., 11 Douglas Crescent
1828		Foster, John, Liverpool
1858		Fraser, A. Campbell, M.A., D.C.L., LL.D., Professor of Logic and Metaphysics in the University of Edinburgh, 20 Chester Street
1867	B. P.	* Fraser, Thomas R., M.D., F.R.C.P.E., F.R.S., Professor of Materia Medica in the University of Edinburgh, 37 Melville Street 150
1885		* Fraser, A. Y., M.A., Secretary to the Mathematical Society of Edinb., 8 Chalmers Street
1867		Gayner, Charles, M.D., Oxford
1880	P.	* Geddes, Patrick, Assistant to the Professor of Botany in the University of Edinburgh, and Lecturer on Zoology at Minto House, 81a Princes Street
1861	B. P.	Geikie, Archibald, LL.D., F.R.S., F.G.S., Director of the Geological Surveys of Great Britain, and Head of the Geological Museum, 28 Jermyn Street, London
1871	B. P.	* Geikie, James, LL.D., F.R.S., F.G.S., Professor of Geology in the University of Edinburgh, 10 Bright Crescent, Newington 155
1886		* Gibson, Alexander, Advocate, 12 Great King Street
1881		* Gibson, G. A., D.Sc., M.B., F.R.C.P.E., F.G.S., 1 Randolph Cliff
1877		* Gibson, John, Ph.D., 20 Warrender Park Crescent
1885	P.	* Gibson, R. J. Harvey, M.A., Demonstrator of Zoology in University College, Liverpool
1870		* Gifford, Hon. Lord, late one of the Senators of the College of Justice, Granton House 160
1879		* Gilray, Thomas, M.A., Professor of English Language and Literature and Modern History in University College, Dundee
1880		* Gilruth, George Ritchie, Surgeon, 67 York Place
1850		Gosset, Major-General W. D., R.E., 70 Edith Road, West Kensington, London
1867		* Graham, Andrew, M.D., R.N., Army and Navy Club, 36 Pall Mall, London, S.W.
1880		* Graham, James, 195 Bath Street, Glasgow 165
1851		Grant, The Rev. James, D.D., D.C.L., 15 Palmerston Place
1883		* Gray, Andrew, M.A., Professor of Physics in University College, Bangor, North Wales
1875		* Gray, Robert, Secretary to the Royal Physical Society, Bank of Scotland House
1880	P.	Gray, Thomas, B.Sc., 17 Hayburn Crescent, Partick Hill, Glasgow
1886		* Greenfield, W. S., M.D., Professor of General Pathology in the University of Edinburgh, 7 Heriot Row 170
1872		* Grieve, David, Lockharton Gardens, Colinton Road, Slateford

Date of Election.		
1884		* Grieve, John, M.A., M.D., F.L.S., 212 St Vincent Street, Glasgow
1886		* Griffiths, Arthur Bower, Ph.D., Principal and Lecturer on Chemistry in the School of Science of the City and County of Leicester, 15 Broadgate, Lincoln
1883		Gunning, R. H., M.D., 30 Hazlitt Road, West Kensington Park, London
1886		* Haddington, The Right Hon. the Earl of, Tyninghame House, Haddington 175
1867		* Haldane, D. R., M.D., F.R.C.P.E., 22 Charlotte Square
1867		* Hallen, James H. B., F.R.C.S.E., F.R.P.S.E., Inspecting Veterinary Surgeon in H.M. Indian Army, 1 Lauriston Gardens
1881	P.	* Hamilton, D. J., M.B., F.R.C.S.E., Professor of Pathological Anatomy in the University of Aberdeen, 1A Albyn Place, Aberdeen
1876	P.	* Hannay, J. Ballantyne, Cove Castle, Loch Long, N.B.
1886		* Hare, Arthur W., M.B., C.M., 21 Ainslie Place 180
1869		Hartley, Sir Charles A., K.C.M.G., Memb. Inst. C.E., 26 Pall Mall, London
1877		Hartley, Walter Noel, F.R.S., Professor of Chemistry, Royal College of Science for Ireland, Dublin
1870		* Harvey, Thomas, M.A., LL.D., Rector of the Edinburgh Academy, 32 George Square
1880	P.	* Haycraft, J. Berry, M.B., B.Sc., Professor of Physiology in Sir Josiah Mason's Science College, Birmingham
1875		Hawkshaw, Sir John, Memb. Inst. C.E., F.R.S., F.G.S., 33 Great George Street, Westminster 185
1870		Heathfield, W. E., F.C.S., 1 Powis Grove, Brighton
1862		Hector, James, C.M.G., M.D., F.R.S., Director of the Geological Survey, Wellington, New Zealand
1876	K. P.	* Heddle, M. Forster, M.D., Emeritus Professor of Chemistry in the University of St Andrews
1884		* Henderson, John, jun., 4 Crown Terrace, Dowanhill, Glasgow
1881	N. P.	* Herdman, W. A., D.Sc., Professor of Natural History in University College, Liverpool 190
1871		Higgins, Charles Hayes, LL.D., Alfred House, Birkenhead
1859		Hills, John, Lieut.-Colonel, Bombay Engineers, C.B., United Service Club, London
1879		Hislop, John, Secretary to the Department of Education, Wellington, New Zealand
1885		Hodgkinson, W. R., Ph.D., Professor of Chemistry, South Kensington Museum, 29 Pembroke Square, London
1828	P.	Home, David Milne, of Milne Graden, LL.D., F.G.S. (VICE-PRESIDENT), 10 York Place 195
1879		* Hood, Thomas H. Cockburn, F.G.S., Walton Hall, Kelso
1881	P.	* Horne, John, F.G.S., Geological Survey of Scotland, 41 Southside Road, Inverness
1883	P.	* Hoyle, William Evans, M.A., M.R.C.S., Office of Challenger Commission, 32 Queen Street
1886		Hunt, Rev. H. G. Bonavia, Mus. B. Oxon., F.R.A.S., F.L.S., La Belle Sauvage, London
1872		* Hunter, Major Charles, Plâs Cöch, Llanfair, Anglesea, and 17 St George's Square, London, S.W. 200
1864		* Hutchison, Robert (Carlowrie Castle), and 29 Chester Street
1855		Inglis, Right Hon. John, LL.D., D.C.L., Lord Justice-General of Scotland, and Chancellor of the University of Edinburgh, 30 Abercromby Place
1882		* Inglis, J. W., Memb. Inst. C.E., Myrtle Bank, Trinity
1874		* Irvine, Alex. Forbes, of Drum, Advocate, Sheriff of Argyll (VICE-PRESIDENT), 25 Castle Terrace
1886		* Irvine, Robert, Granton, Edinburgh 205

Date of Election.		
1875		Jack, William, M.A., Professor of Mathematics in the University of Glasgow
1882		* Jamieson, A., Assoc. Memb. Inst. C.E., Principal of College of Science and Arts, Glasgow
1860		Jamieson, George A., 24 St Andrew Square
1880		Japp, A. H., LL.D., The Limes, Elmstead, near Colchester
1865		* Jenner, Charles, Easter Duddingston Lodge 210
1869		Johnston, John Wilson, M.D., Surgeon-Major, 11 Windsor Street
1867		* Johnston, T. B., F.R.G.S., Geographer to the Queen, 9 Claremont Crescent
1874		Jones, Francis, Lecturer on Chemistry, Monton Place, Manchester
1877		* Jolly, William, H.M. Inspector of Schools, F.G.S., Ardgowan, Pollokshields
1866		* Keiller, Alexander, M.D., F.R.C.P.E., LL.D., 21 Queen Street 215
1886		* Kidston, Robert, F.G.S., 24 Victoria Place, Stirling
1877		* King, James, of Campsie, LL.D., 12 Claremont Terrace, Glasgow
1880		* King, W. F., Lonend, Trinity
1883		* Kinnear, The Hon. Lord, one of the Senators of the College of Justice, 2 Moray Place
1878		* Kintore, The Right Hon. the Earl of, M.A. Cantab., Keith Hall, Inglismaldie Castle, Laurencekirk, N.B. 220
1875		* Kirkwood, Anderson, LL.D., 7 Melville Terrace, Stirling
1880	P.	* Knott, C. G., D.Sc., Prof. of Natural Philosophy in the Imperial University of Tokio, Japan
1875		* L'Amy, John Ramsay, of Dunkenny, Forfarshire, 107 Cromwell Road, London, S.W.
1886		* Laing, Rev. George, 17 Buckingham Terrace
1878		* Lang, P. R. Scott, M.A., B.Sc., Professor of Mathematics in the University of St Andrews 225
1885		* Laurie, A. P., B.A., B.Sc., Nairn Lodge, Duddingston, Edinburgh
1870		* Laurie, Simon S., M.A., Professor of Education in the University of Edinburgh, Nairn Lodge, Duddingston
1881		* Lawson, Robert, M.D., Deputy-Commissioner in Lunacy, 24 Mayfield Terrace
1872		* Lee, Alexander H., C.E., Blairhoyle, Stirling
1872		* Lee, The Hon. Lord, one of the Senators of the College of Justice, Duddingstone House, Edinburgh 230
1882		* Leslie, Alexander, Memb. Inst. C.E., 12 Greenhill Terrace
1883		* Leslie George, M.B., C.M., Old Manse, Falkirk
1863		* Leslie, Hon. G. Waldegrave, Leslie House, Leslie
1858		Leslie, James, Memb. Inst. C.E., 2 Charlotte Square
1874	P.	* Letts, E. A., Ph.D., F.I.C., F.C.S., Professor of Chemistry, Queen's College, Belfast 235
1870	B. P.	* Lister, Sir Joseph, Bart., M.D., F.R.C.S.L., F.R.C.S.E., LL.D., D.C.L., F.R.S., Professor of Clinical Surgery, King's College, Surgeon Extraordinary to the Queen, 12 Park Crescent, Portland Place, London, N.W.
1882		* Livingston, Josiah, 4 Minto Street
1861		Lorimer, James, M.A., Advocate, Professor of Public Law in the University of Edinburgh, 1 Bruntsfield Crescent
1884		* Low, George M., Actuary, 19 Learmonth Terrace
1849		Lowe, W. H., M.D., F.R.C.P.E., Woodcote, Inner Park, Wimbledon 240
1886		Lyster, George Fosbery, Memb. Inst. C.E., Gisburn House, Liverpool
1855		Macadam, Stevenson, Ph.D., Lecturer on Chemistry, Surgeons' Hall, Edinburgh, 11 East Brighton Crescent, Portobello
1885		* M'Bride, Charles, M.D., Wigtown
1883		* M'Bride, P., M.D., F.R.C.P.E., 16 Chester Street

Date of Election.		
1867		* M'Candlish, John M., W.S., 27 Drumsheugh Gardens 245
1886		* Macdonald, The Right Hon. J. H. A., C.B., Q.C., M.P., LL.D., M.S.T.E. and E., Lord Advocate of Scotland, 15 Abercromby Place
1886		* Macdonald, William J., M.A., 4 Polwarth Gardens
1847		Macdonald, W. Macdonald, of St Martin's, Perth
1878		* MacDougall, Alan, M.I.C.E., Mail Building, 52 King Street West, Toronto, Canada
1878	P.	Macfarlane, Alex., M.A., D.Sc., Professor of Physics in the University of the State of Texas, Austin, Texas 250
1885	P.	* Macfarlane, J. M., D.Sc., 15 Scotland Street
1877		* Macfie, Robert A., Dreghorn Castle, Colinton
1878		* M'Gowan, George, F.I.C., Ph.D., University College of North Wales, Bangor
1886		* MacGregor, Rev. J., D.D., 11 Cumin Place, Grange
1880	P.	MacGregor, J. Gordon, M.A., D.Sc., Professor of Physics in Dalhousie College, Halifax, Nova Scotia 255
1879		* M'Grigor, Alexander Bennett, LL.D., 19 Woodside Terrace, Glasgow
1869	N. P.	* M'Intosh, William Carmichael, M.D., LL.D., F.R.S., F.L.S., Professor of Natural History in the University of St Andrews, 2 Abbotsford Crescent, St Andrews
1882		* Mackay, John Sturgeon, M.A., Mathematical Master in the Edinburgh Academy, 69 Northumberland Street
1873	P.	* M'Kendrick, John G., M.D., F.R.C.P.E., F.R.S., Professor of the Institutes of Medicine in the University of Glasgow
1840		Mackenzie, John, New Club, Princes Street 260
1843	P.	Maclagan, Sir Douglas, M.D., President of the Royal College of Physicians, Edinburgh, and F.R.C.S.E., Professor of Medical Jurisprudence in the University of Edinburgh (VICE-PRESIDENT), 28 Heriot Row
1853		Maclagan, General R., Royal Engineers, 86 Lexham Gardens, London, W.
1869		* Maclagan, R. Craig, M.D., 5 Coates Crescent
1864		* M'Lagan, Peter, of Pumpherston, M.P., Clifton Hall, Ratho
1869		* M'Laren, The Hon. Lord, LL.D. Edin. and Glasg., F.R.A.S., one of the Senators of the College of Justice (VICE-PRESIDENT), 46 Moray Place 265
1870		* Macleod, Geo. H. B., M.D., F.R.C.S.E., Regius Prof. of Surgery in the University of Glasgow, and Surgeon in Ordinary to the Queen in Scotland, 10 Woodside Crescent, Glasgow
1876		* Macleod, Rev. Norman, D.D., 7 Royal Circus
1883		* Macleod, W. Bowman, L.D.S., 16 George Square
1872		* Macmillan, Rev. Hugh, D.D., LL.D., Seafield, Greenock
1876		* Macmillan, John, M.A., B.Sc., Mathematical Master, Perth Academy 270
1884		* Macpherson, Rev. J. Gordon, M.A., D.Sc., Ruthven Manse, Insigle
1883		* M'Roberts, George, F.C.S., Ardeer, Stevenston, Ayrshire
1858		Malcolm, R. B., M.D., F.R.C.P.E., 126 George Street
1880	P.	Marsden, R. Sydney, M.B., C.M., D.Sc., F.I.C., F.C.S., Rillington, near York.
1882	P.	Marshall, D. H., M.A., Professor of Physics in Queen's University and College, Kingston, Ontario, Canada 275
1869		Marshall, Henry, M.D., Clifton, Bristol
1864		* Marwick, James David, LL.D., Town-Clerk, Glasgow
1866		* Masson, David, LL.D., Professor of Rhetoric and English Literature in the University of Edinburgh, 58 Great King Street
1885	P.	* Masson, Orme, D Sc., Professor of Chemistry in the University of Melbourne
1883		* Matthews, James Duncan, Springhill, Aberdeen 280

Date of Election.		
1885		* Mill, Hugh Robt., D.Sc., F.C.S., Scottish Marine Station, Granton, 3 Glenorchy Terrace, Edinburgh
1886		* Miller, Hugh, H.M. Geological Survey, 51 Lauriston Place
1852		Miller, Thomas, M.A., LL.D., Emeritus Rector of Perth Academy, Inchbank House, Perth
1885		* Miller, William, S.S.C., 59 George Square
1833		Milne, Admiral Sir Alexander, Bart., G.C.B., Inveresk 285
1886		* Milne, William, M.A., B.Sc., Mathematical and Science Teacher, High School, Glasgow
1866		* Mitchell, Arthur, C.B., M.A., M.D., LL.D., Commissioner in Lunacy, 34 Drummond Place
1865		* Moir, John J. A., M.D., F.R.C.P.E., 52 Castle Street
1870		* Moncreiff, The Right Hon. Lord, of Tullibole, Lord Justice-Clerk, LL.D. (Honorary Vice-President), 15 Great Stuart Street
1871		* Moncrieff, Rev. Canon William Scott, of Fossaway, Christ's Church Vicarage, Bishop-Wearmouth, Sunderland 290
1868		* Montgomery, Very Rev. Dean, M.A., D.D., 17 Atholl Crescent
1879		* Morrison, J. B. Brown, of Finderlie and Murie, The Old House, Harrow-on-the-Hill
1877	P.	* Morrison, Robert Milner, D.Sc., F.I.C., Nether Liberton House
1873		* Muir, M. M. Pattison, Prælector on Chemistry, Caius College, Cambridge
1874	K.P.	* Muir, Thomas, M.A., LL.D., Mathematical Master, High School, Glasgow, Beechcroft, Bishopton, Glasgow 295
1870		* Munn, David, M.A., Mathematical Master, Royal High School
1857		Murray, John Ivor, M.D., F.R.C.S.E., M.R.C.P.E., 24 Huntriss Row, Scarborough
1877	N. P.	* Murray, John, Ph.D., Director of the Challenger Expedition Commission, 32 Queen Street, and United Service Club (Vice-President)
1884		Mylne, R. W., C.E., F.R.S., 7 Whitehall Place, London, S.W.
1877		* Napier, John, 23 Portman Square, London 300
1866		* Nelson, Thomas, St Leonard's, Dalkeith Road
1883		* Newcombe, Henry, F.R.C.S.E., 5 Dalrymple Crescent, Edinburgh
1884		* Nicholson, J. Shield, Professor of Political Economy in the University of Edinburgh Eden Lodge, Eden Lane, Newbattle Terrace
1880	P.	* Nicol, W. W. J., M.A., B.Sc., Lecturer on Chemistry, Sir Josiah Mason's College, Birmingham
1878		Norris, Richard, M.D., Professor of Physiology, Queen's College, Birmingham 305
1886		Oliver, James, M.B. Edin., M.R.C.P. Lond., Montague Street, Russell Square, London
1884		* Omond, Robert Traill, Superintendent of Ben Nevis Observatory, Fort-William, Inverness
1877		Panton, George A., 95 Colmore Row, Birmingham
1886		* Paton, D. Noel, M.D., B.Sc., 4 Walker Street
1881	N.P.	* Peach, B. N., F.G.S., Acting Palæontologist of the Geological Survey of Scotland, 8 Annandale Street 310
1863		* Peddie, Alexander, M.D., F.R.C.P.E., 15 Rutland Street
1886		* Peebles, D. Bruce, Tay House, Bonnington, Edinburgh
1869		Pender, John, 18 Arlington Street, Piccadilly, London
1883		Phillips, Charles D. F., M.D., 10 Henrietta Street, Cavendish Square, London, W.
1859	P.	Playfair, The Right Hon. Sir Lyon, C.B., LL.D., F.R.S., M.P., 68 Onslow Gardens, London 315
1877		Pole, William, Memb. Inst. C.E., F.R.S., Mus. Doc., 31 Parliament Street, Westminster, S.W.

Date of Election.		
1886		* Pollock, Charles Frederick, M.D., F.R.C.S.E., 1 Buckingham Terrace, Hillhead, Glasgow
1874		Powell, Baden Henry Baden-, Forest Department, India
1852		Powell, Eyre B., C.S.I., M.A., 28 Park Road, Haverstock Hill, Hampstead, London
1880		* Prentice, Charles, C.A., Actuary, 8 St Bernard's Crescent 320
1875		Prevost, E. W., Ph.D., Ellesmere, Salop
1849		Primrose, Hon. B. F., C.B., 22 Moray Place
1885		* Pringle, James, Provost of Leith, 7 Claremont Park, Leith
1882		* Pryde, David, M.A., LL.D., Head Master of the Ladies' College, 10 Fettes Row, Edinburgh
1885		* Pullar, J. F., Rosebank, Perth 325
1880		* Pullar, Robert, Tayside, Perth
1884		Ramsay, E. Peirson, F.L.S., F.R.G.S., F.G.S., Curator of Australian Museum, Sydney, New South Wales
1882		* Rattray, James Clerk, M.D., 61 Grange Loan
1885	P.	* Rattray, John, M.A., B.Sc., 15 Scotland Street
1869		Raven, Rev. Thomas Milville, M.A., The Vicarage, Crakehall, Bedale 330
1883		* Readman, J. B., 9 Moray Place
1875		* Richardson, Ralph, W.S., 10 Magdala Place
1872		Ricarde-Seaver, Major F. Ignacio, Conservative Club, St James' Street, London, S.W., and 2 Rue Lafitte, Boulevard des Italiens, Paris
1883		* Ritchie, R. Peel, M.D., F.R.C.P.E., 1 Melville Crescent
1877		* Roberton, James, LL.D., Professor of Conveyancing in the University of Glasgow, 1 Park Terrace East, Glasgow 335
1880		Roberts, D. Lloyd, M.D., F.R.C.P.L., 23 St John Street, Manchester
1872		* Robertson D. M. C. L. Argyll, M.D., F.R.C.S.E., Surgeon Oculist to the Queen for Scotland, and President of the Royal College of Surgeons, 18 Charlotte Square
1859		Robertson, George, Memb. Inst. C.E., Athenæum Club, Pall Mall, London
1886		* Robertson, J. P. B., Q.C., M.P., 19 Drumsheugh Gardens
1877	P.	* Robinson, George Carr, F.I.C., Lecturer on Chemistry in the Royal Institution, Hull 340
1881		* Rogerson, John Johnston, B.A., LL.B., Merchiston Castle Academy
1862	P.	Ronalds, Edmund, LL.D., Bonnington House, Bonnington Road
1881		Rosebery, The Right Hon. the Earl of, LL.D., Dalmeny
1880		Rowland, L. L., M.A., M.D., President of the Oregon State Medical Society, and Professor of Physiology and Microscopy in Williamette University, Salem, Oregon
1852		Russell, Alexander James, C.S., 9 Shandwick Place 345
1880		* Russell, J. A., M.A., B.Sc., M.B., F.R.C.P.E., Woodville, Canaan Lane
1869	P.	* Rutherford, Wm., M.D., F.R.C.P.E., F.R.S., Professor of the Institutes of Medicine in the University of Edinburgh, 14 Douglas Crescent
1863		* Sanderson, James, Deputy Inspector-General of Hospitals, F.R.C.S.E., 8 Manor Place
1864		Sandford, The Right Rev. D. F., LL.D., Bishop of Tasmania
1849	B. P.	Sang, Edward, C.E., LL.D., Secretary to the Royal Scottish Society of Arts, 31 Mayfield Road 350
1846		Schmitz, Leonard, LL.D., 81 Linden Gardens, London, W.
1885		Scott, Alexander, M.A., D.Sc., 4 North Bailey, Durham
1880		Scott, J. H., M.B., C.M., M.R.C.S., Professor of Anatomy in the University of Otago, New Zealand
1875		Scott, Michael, Memb. Inst. C.E., 22 Mount Ephraim, Tunbridge Wells

Date of Election.		
1864		* Sellar, W. Y., M.A., LL.D., Professor of Humanity in the University of Edinburgh, 15 Buckingham Terrace 355
1872		* Seton, George, M.A., Advocate, 42 Greenhill Gardens
1872		* Sibbald, John, M.D., Commissioner in Lunacy, 3 St Margaret's Road, Whitehouse Loan
1870		* Sime, James, M.A., South Park, Fountainhall Road
1871		* Simpson, A. R., M.D., F.R.C.P.E., Professor of Midwifery in the University of Edinburgh, 52 Queen Street
1859	P.	Skene, Wm. F., W.S., LL.D., D.C.L., Historiographer-Royal for Scotland, 27 Inverleith Row 360
1876		* Skinner, William, W.S., Town-Clerk of Edinburgh, 35 George Square
1868		* Smith, Adam Gillies, C.A. (Treasurer), 64 Princes Street
1882	P.	Smith, C. Michie, B.Sc., Professor of Physical Science, Christian College, Madras, India
1885		* Smith, George, F.C.S., Polmont Station, N.B.
1883		Smith, James Greig, M.A., M.B., 16 Victoria Square, Clifton 365
1871		* Smith, John, M.D., LL.D., F.R.C.S.E., 11 Wemyss Place
1855		Smith, Robert Mackay, 4 Bellevue Crescent
1886		* Smith, Colonel R. Murdoch, R.E., Director of Museum of Science and Art, Edinburgh
1871	P.	* Smith, Rev. W. Robertson, M.A., LL.D., Librarian to the University of Cambridge
1880		Smith, W. Robert, M.D., 74 Great Russell Street, Bloomsbury Square, London 370
1846	K.B. P.	Smyth, Piazzi, Professor of Practical Astronomy in the University of Edinburgh, and Astronomer-Royal for Scotland, 15 Royal Terrace
1880		Sollas, W. J., M.A., D.Sc., late Fellow of St John's College, Cambridge, and Professor of Geology and Mineralogy in the University of Dublin, 4 Clyde Road, Dublin
1882		* Sorley, James, F.F.A., C.A., 2 Dean Park Crescent
1874	P.	* Sprague, T. B., M.A., 29 Buckingham Terrace
1850	P.	Stark, James, M.D., F.R.C.P.E., of Huntfield, Underwood, Bridge of Allan 375
1885		* Steggall, J. E. A., Prof. of Mathematics and Natural Philosophy in University Coll., Dundee
1886		* Stevenson, C. A., B.Sc., C.E., 45 Melville Street
18[illegible]		* Stevenson, David Alan, B.Sc., C.E., 45 Melville Street
1877		* Stevenson, James, F.R.G.S., 4 Woodside Crescent, Glasgow
1868		Stevenson, John J., Red House, Bayswater Hill, London, W. 380
1848	P.	Stevenson, Thomas, Memb. Inst. C.E., F.G.S. (Honorary Vice-President), 84 George Street
1868		Stewart, Colonel J. H. M. Shaw, Royal Engineers, Madras
1878		* Stewart, James R., M.A., 10 Salisbury Road
1866		* Stewart, T. Grainger, M.D., F.R.C.P.E., Professor of the Practice of Physic in the University of Edinburgh, 19 Charlotte Square
1873		* Stewart, Walter, 22 Torphichen Street 385
1848		Stirling, Patrick J., LL.D., Kippendavie House, Dunblane
1877		* Stirling, William, Sc.D., M.D., Brackenbury Professor of Physiology and Histology in Owens College and Victoria University, Manchester
1823		Stuart, Captain T. D., H.M.I.S.
1870		* Swan, Patrick Don, Provost of Kirkcaldy
1848	P.	Swan, Wm., LL.D., Emeritus Professor of Natural Philosophy in the University of St Andrews, President of the Royal Scottish Society of Arts, Ardchapel, Helensburgh 390
1844		Swinton, A. Campbell, of Kimmerghame, LL.D., Duns
1875		Syme, James, 9 Drumsheugh Gardens
1885		* Symington, Johnson, M.B., F.R.C.S.E., 2 Greenhill Park

Date of Election.		
1872		Tait, the Rev. A., D.D., LL.D., Canon of Tuam, Moylough Rectory, Ballinasloe, Ireland
1861	K.P.	Tait, P. Guthrie, M.A., Professor of Natural Philosophy in the University of Edinburgh (General Secretary), 38 George Square 395
1870		* Tatlock, Robert R., City Analyst's Office, 138 Bath Street, Glasgow
1872		* Teape, Rev. Charles R., M.A., Ph.D., 15 Findhorn Place
1873		* Tennent, Robert, 23 Buckingham Terrace
1885		* Thompson, D'Arcy W., Professor of Natural History in University College, Dundee
1884		* Thoms, George Hunter, of Aberlemno, Advocate, Sheriff of the Counties of Orkney and Zetland, 13 Charlotte Square 400
1870		* Thomson, Rev. Andrew, D.D., 63 Northumberland Street
1875		* Thomson, James, LL.D., F.R.S., Professor of Engineering in the University of Glasgow, 2 Florentine Gardens, Hillhead, Glasgow
1880		Thomson, John Millar, King's College, London
1863		* Thomson, Murray, M.D., Professor of Chemistry, Thomason College, Roorkee, India
1870		* Thomson, Spencer C., Actuary, 10 Chester Street 405
1847	K.P.	Thomson, Sir William, LL.D., D.C.L., F.R.S. (President), Regius Professor of Natural Philosophy in the University of Glasgow, Foreign Associate of Institute of France, and Member of the Prussian Order *Pour le Mérite*
1882		Thomson, William, M.A., B.Sc., Professor of Mathematics in University College, Stellenbosch, Cape Colony
1870		* Thomson, Wm. Burns, F.R.C.P.E., F.R.C.S.E., 110 Newington Green Road, London, N.
1876		Thomson, William, Royal Institution, Manchester
1878		Thorburn, Robert Macfie, Uddevalla, Sweden 410
1874	N.P.	* Traquair, R. H., M.D., F.R.S., F.G S., Keeper of the Natural History Collections in the Museum of Science and Art, Edinburgh, 8 Dean Park Crescent
1874		* Tuke, J. Batty, M.D., F.R.C.P.E., 20 Charlotte Square
1879		* Turnbull, John, of Abbey St Bathans, W.S., 49 George Square
1861	N.P.	Turner, Sir William, M.B., F.R.C.S.E., F.R.S., Professor of Anatomy in the University of Edinburgh, and President of the Royal Physical Society (Secretary), 6 Eton Terrace
1877		* Underhill, Charles E., B.A., M.B., F.R.C.P.E., F.R.C.S.E., 8 Coates Crescent 415
1875		Vincent, Charles Wilson, Royal Institution, Albemarle Street, London
1867		* Waddell, Peter, 5 Claremont Park, Leith
1873		* Walker, Robert, M.A., University, Aberdeen
1886		* Wallace, Robert, Professor of Agriculture and Rural Economy in the University of Edin.
1864		* Wallace, William, Ph.D., City Analyst's Office, 138 Bath Street, Glasgow 420
1883		* Watson, Charles, Redhall, Slateford
1870		* Watson, James, C.A., 45 Charlotte Square
1866		* Watson, John K., 14 Blackford Road
1866		* Watson, Patrick Heron, M.D., F.R.C.P.E., F.R.C.S.E., LL.D., 16 Charlotte Square
1862	P.	Watson, Rev. Robert Boog, B.A., Free Church Manse, Cardross, Dumbartonshire 425
1873		Welsh, David, Major-General (Retired), R.A., 1 Barton Terrace, Dawlish
1840		Welwood, Allan A. Maconochie, LL.D., of Meadowbank and Garvoch, Kirknewton
1882		* Wenley, James A., Treasurer of the Bank of Scotland, 5 Drumsheugh Gardens
1876		White, Rev. Francis Le Grix, M.A., F.G.S., Leaming-on-Ulleswater, Penrith
1881		Whitehead, Walter, F.R.C.S.E., 202 Oxford Road, Manchester 430

Date of Election.	
1883	Wickham, R. H. B., F.R.C.S.E., Borough Lunatic Asylum, Newcastle-on-Tyne
1879	* Will, John Charles Ogilvie, M.D., 305 Union Street, Aberdeen
1868	* Williams, W., Principal and Professor of Veterinary Medicine and Surgery, New Veterinary College, Leith Walk
1879	* Wilson, Andrew, Ph.D., Lecturer on Zoology and Comparative Anatomy in the Edinburgh Medical School, 118 Gilmore Place
1877	* Wilson, Charles E., M.A., LL.D., H.M. Senior Inspector of Schools for Scotland, 19 Palmerston Place 435
1878	* Wilson, Rev. John, M.A., Bannockburn Academy
1875	Wilson, Daniel, LL.D., President of the University of Toronto, and Professor of English Literature in that University
1882	Wilson, George, M.A., M.D., 23 Claremont Road, Leamington
1834	Wilson, Isaac, M.D.
1847	Wilson, John, LL.D., Emeritus Professor of Agriculture in the University of Edinburgh 440
1870	Winzer, John, Chief Surveyor, Civil Service, Ceylon, 7 Dryden Place, Newington
1880	* Wise, Thos. Alex., M.D., F.R.C.P.E., F.R.A.S., Thornton, the Beulah, Upper Norwood
1886	* Woodhead, German Sims, M.D., 6 Marchhall Crescent
1884	Woods, G. A., M.R.C.S., Carlton House, 57 Houghton Street, Southport
1864	* Wyld, Robert S., LL.D , 19 Inverleith Row 445
1882	* Young, Andrew, 22 Elm Row
1882	* Young, Frank W., F.C.S., Lecturer on Natural Science, High School, Dundee, Woodmuir Park, West Newport, Fife
1882	* Young, Thomas Graham, Durris, Aberdeenshire 448

LIST OF HONORARY FELLOWS

AT NOVEMBER 1884.

His Royal Highness The PRINCE OF WAEES.

FOREIGNERS (LIMITED TO THIRTY-SIX BY LAW X.).

Elected.		
1884	Pierre J. van Beneden,	*Louvain.*
1864	Robert Wilhelm Bunsen,	*Heidelberg.*
1867	Michel Eugène Chevreul,	*Paris.*
1858	James D. Dana,	*New Haven, Conn.*
1877	Alphonse de Candolle,	*Geneva.*
1883	Luigi Cremona,	*Rome.*
1879	Franz Cornelius Donders,	*Utrecht.*
1877	Carl Gegenbaur,	*Heidelberg.*
1879	Asa Gray,	*Harvard University.*
1883	Julius Hann,	*Vienna.*
1884	Charles Hermite,	*Paris.*
1864	Hermann Ludwig Ferdinand von Helmholtz,	*Berlin.*
1879	Jules Janssen,	*Paris.*
1875	August Kekulé,	*Bonn.*
1868	Gustav Robert Kirchhoff,	*Berlin.*
1875	Hermann Kolbe,	*Leipzig.*
1864	Albert Kölliker,	*Würzburg.*
1875	Ernst Eduard Kummer,	*Berlin.*
1876	Ferdinand de Lesseps,	*Paris.*
1864	Rudolph Leuckart,	*Leipzig.*
1881	Seven Lovén,	*Stockholm.*
1876	Carl Ludwig,	*Leipzig.*
1878	J. N. Madvig,	*Copenhagen.*
1855	Henry Milne-Edwards,	*Paris.*
1864	Theodore Mommsen,	*Berlin.*
1881	Simon Newcomb,	*Washington.*
1874	Louis Pasteur,	*Paris.*
1864	Carl Theodor von Siebold,	*Munich.*
1881	Johannes Iapetus Smith Steenstrup,	*Copenhagen.*
1878	Otto Wilhelm Struve,	*Pulkowa.*
1855	Bernard Studer,	*Bern.*
1874	Otto Torell,	*Lund.*
1868	Rudolph Virchow,	*Berlin.*
1874	Wilhelm Eduard Weber,	*Göttingen.*

Total, 34.

BRITISH SUBJECTS (LIMITED TO TWENTY BY LAW X.).

Elected.		
1849	John Couch Adams, LL.D., F.R.S., Corresp. Mem. Inst. France,	*Cambridge.*
1835	Sir George Biddell Airy, K.C.B., M.A., LL.D., D.C.L., F.R.S., Foreign Associate Inst. France,	*Greenwich.*
1870	Thomas Andrews, M.D., LL.D., F.R.S.,	*Belfast.*
1865	Arthur Cayley, LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. France,	*Cambridge.*
1884	Edward Frankland, D.C.L., LL.D., F.R.S.,	*London.*
1874	John Anthony Froude, LL.D.,	*London.*
1881	The Hon. Justice Sir William Robert Grove, M.A., LL.D., D.C.L., F.R.S.,	*London.*
1883	Sir Joseph Dalton Hooker, K.C.S.I., C.B., M.D., D.C.L., LL.D., F.R.S., F.G.S., Corresp. Mem. Inst. France, Director of the Royal Gardens, Kew,	*London.*
1884	William Huggins, LL.D., D.C.L., F.R.S.,	*London.*
1876	Thomas Henry Huxley, LL.D., D.C.L., *P.*R.S., F.L.S., F.L.S., F.G.S., Corresp. Mem. Inst. France,	*London.*
1867	James Prescott Joule, LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. France,	*Manchester.*
1845	Sir Richard Owen, K.C.B., M.D., LL.D., D.C.L., F.R.S., Foreign Associate Inst. France,	*London.*
1881	The Rev. George Salmon, D.D., LL.D., D.C.L., F.R.S., Foreign Associate of the Institute of France,	*Dublin.*
1884	J. S. Burdon Sanderson, M.D., LL.D., F.R.S.,	*Oxford.*
1878	Balfour Stewart, M.A., LL.D., F.R.S.,	*Manchester.*
1864	George Gabriel Stokes, M.A., LL.D., D.C.L., Sec. R.S., Corresp. Mem. Inst. France,	*Cambridge.*
1874	James Joseph Sylvester, M.A., LL.D., F.R.S., Corresp. Mem. Inst. France,	*Oxford.*
1864	The Right Hon. Lord Tennyson, D.C.L., LL.D., F.R.S., Poet Laureate,	*Isle of Wight.*
1883	Alexander William Williamson, LL.D., F.R.S., V.P.C.S., Corresp. Mem. Inst. France,	*London.*
1883	Colonel Henry Yule, C.B., LL.D., Member of the Council of India,	*London.*

Total, 20.

LIST OF HONORARY FELLOWS

AT NOVEMBER 1885.

His Royal Highness The PRINCE OF WALES.

FOREIGNERS (LIMITED TO THIRTY-SIX BY LAW X.).

Elected.		
1884	Pierre J. van Beneden,	*Louvain.*
1864	Robert Wilhelm Bunsen,	*Heidelberg.*
1867	Michel Eugène Chevreul,	*Paris.*
1858	James D. Dana,	*New Haven, Conn.*
1877	Alphonse De Candolle,	*Geneva.*
1883	Luigi Cremona,	*Rome.*
1879	Franz Cornelius Donders,	*Utrecht.*
1877	Carl Gegenbaur,	*Heidelberg.*
1879	Asa Gray,	*Harvard University.*
1883	Julius Hann,	*Vienna.*
1884	Charles Hermite,	*Paris.*
1864	Hermann Ludwig Ferdinand von Helmholtz,	*Berlin.*
1879	Jules Janssen,	*Paris.*
1875	August Kekulé,	*Bonn.*
1868	Gustav Robert Kirchhoff,	*Berlin.*
1875	Hermann Kolbe,	*Leipzig.*
1864	Albert Kölliker,	*Würzburg.*
1875	Ernst Eduard Kummer,	*Berlin.*
1876	Ferdinand de Lesseps,	*Paris.*
1864	Rudolph Leuckart,	*Leipzig.*
1881	Sven Lovén,	*Stockholm.*
1876	Carl Ludwig,	*Leipzig.*
1878	J. N. Madvig,	*Copenhagen.*
1864	Theodore Mommsen,	*Berlin.*
1881	Simon Newcomb,	*Washington.*
1874	Louis Pasteur,	*Paris.*
1881	Johannes Iapetus Smith Steenstrup,	*Copenhagen.*
1878	Otto Wilhelm Struve,	*Pulkowa.*
1855	Bernard Studer,	*Bern.*
1874	Otto Torell,	*Lund.*
1868	Rudolph Virchow,	*Berlin.*
1873	Wilhelm Eduard Weber,	*Göttingen.*

Total, 32.

BRITISH SUBJECTS (LIMITED TO TWENTY BY LAW X.).

Elected.		
1849	John Couch Adams, LL.D., F.R.S., Corresp. Mem. Inst. France,	*Cambridge.*
1835	Sir George Biddell Airy, K.C.B., M.A., LL.D., D.C.L., F.R.S., Foreign Associate Inst. France,	*Greenwich.*
1870	Thomas Andrews, M.D., LL.D., F.R.S.,	*Belfast.*
1865	Arthur Cayley, LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. France,	*Cambridge.*
1884	Edward Frankland, D.C.L., LL.D., F.R.S.,	*London.*
1874	John Anthony Froude, LL.D.,	*London.*
1881	The Hon. Justice Sir William Robert Grove, M.A., LL.D., D.C.L., F.R.S.,	*London.*
1883	Sir Joseph Dalton Hooker, K.C.S.I., C.B., M.D., D.C.L., LL.D., F.R.S., F.G.S., Corresp. Mem. Inst. France, Director of the Royal Gardens, Kew,	*London.*
1884	William Huggins, LL.D., D.C.L., F.R.S.,	*London.*
1876	Thomas Henry Huxley, LL.D., D.C.L., F.R.S., F.L.S., F.Z.S., F.G.S., Corresp. Mem. Inst. France,	*London.*
1867	James Prescott Joule, LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. France,	*Manchester.*
1845	Sir Richard Owen, K.C.B., M.D., LL.D., D.C.L., F.R.S., Foreign Associate Inst. France,	*London.*
1881	The Rev. George Salmon, D.D., LL.D., D.C.L., F.R.S., Foreign Associate of the Institute of France,	*Dublin.*
1884	J. S. Burdon Sanderson, M.D., LL.D., F.R.S.,	*Oxford.*
1878	Balfour Stewart, M.A., LL.D., F.R.S.,	*Manchester.*
1864	George Gabriel Stokes, M.A., LL.D., D.C.L., Sec. R.S., Corresp. Mem. Inst. France,	*Cambridge.*
1874	James Joseph Sylvester, M.A., LL.D., F.R.S., Corresp. Mem. Inst. France,	*Oxford.*
1864	The Right Hon. Lord Tennyson, D.C.L., LL.D., F.R.S., Poet Laureate,	*Isle of Wight.*
1883	Alexander William Williamson, LL.D., F.R.S., V.P.C.S., Corresp. Mem. Inst. France,	*London.*
1883	Colonel Henry Yule, C.B., LL.D., Member of the Council of India,	*London.*

Total, 20.

LIST OF HONORARY FELLOWS

AT NOVEMBER 1886.

His Royal Highness The PRINCE OF WALES.

FOREIGNERS (LIMITED TO THIRTY-SIX BY LAW X.)

Elected.		
1884	Pierre J. van Beneden,	*Louvain.*
1864	Robert Wilhelm Bunsen,	*Heidelberg.*
1867	Michel Eugène Chevreul,	*Paris.*
1858	James D. Dana,	*New Haven, Conn.*
1877	Alphonse De Candolle,	*Geneva.*
1883	Luigi Cremona,	*Rome.*
1879	Franz Cornelius Donders,	*Utrecht.*
1877	Carl Gegenbaur,	*Heidelberg*
1879	Asa Gray,	*Harvard University.*
1883	Julius Hann,	*Vienna.*
1884	Charles Hermite	*Paris.*
1864	Hermann Ludwig Ferdinand von Helmholtz,	*Berlin.*
1879	Jules Janssen,	*Paris.*
1875	August Kekulé,	*Bonn.*
1868	Gustav Robert Kirchhoff	*Berlin.*
1875	Hermann Kolbe,	*Leipzig.*
1864	Albert Kölliker,	*Würzburg.*
1875	Ernst Eduard Kummer,	*Berlin.*
1876	Ferdinand de Lesseps,	*Paris.*
1864	Rudolph Leuckart,	*Leipzig.*
1881	Sven Lovén,	*Stockholm.*
1876	Carl Ludwig,	*Leipzig.*
1878	J. N. Madvig,	*Copenhagen.*
1886	Alphonse Milne-Edwards,	*Paris.*
1864	Theodore Mommsen,	*Berlin.*
1881	Simon Newcomb,	*Washington.*
1886	H. A. Newton,	*Yale College.*
1874	Louis Pasteur,	*Paris.*
1886	L'Abbé Renard,	*Louvain.*
1881	Johannes Iapetus Smith Steenstrup,	*Copenhagen.*
1878	Otto Wilhelm Struve,	*Pulkowa.*
1855	Bernard Studer,	*Bern.*
1886	Tobias Robert Thalen,	*Upsala.*
1874	Otto Torell,	*Lund.*
1868	Rudolph Virchow,	*Berlin.*
1874	Wilhelm Eduard Weber,	*Göttingen.*

Total, 36.

BRITISH SUBJECTS (LIMITED TO TWENTY BY LAW X.).

Elected.		
1849	John Couch Adams, LL.D., F.R.S., Corresp. Mem. Inst. France,	*Cambridge.*
1835	Sir George Biddell Airy, K.C.B., M.A., LL.D., D.C.L., F.R.S., Foreign Associate Inst., France,	*Greenwich.*
1865	Arthur Cayley, LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. France,	*Cambridge.*
1884	Edward Frankland, D.C.L., LL.D., F.R.S.,	*London.*
1874	John Anthony Froude, LL.D.,	*London.*
1881	The Hon. Justice Sir William Robert Grove, M.A., LL.D., D.C.L., F.R.S.,	*London.*
1883	Sir Joseph Dalton Hooker, K.C.S.I., C.B., M.D., D.C.L., LL.D., F.R.S., F.G.S., Corresp. Mem. Inst. France,	*London.*
1884	William Huggins, LL.D., D.C.L., F.R.S.,	*London.*
1876	Thomas Henry Huxley, LL.D., D.C.L., F.R.S., F.L.S., F.Z.S., F.G.S., Corresp. Mem. Inst. France,	*London.*
1867	James Prescott Joule, LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. France,	*Manchester.*
1845	Sir Richard Owen, K.C.B., M.D., LL.D., D.C.L., F.R.S., Foreign Associate Inst. France,	*London.*
1886	The Lord Rayleigh, D.C.L., LL.D., Sec. R.S.,	*London.*
1881	The Rev. George Salmon, D.D., LL.D., D.C.L., F.R.S., Foreign Associate of the Institute of France,	*Dublin.*
1884	J. S. Burdon Sanderson, M.D., LL.D., F.R.S.,	*Oxford.*
1878	Balfour Stewart, M.A., LL.D., F.R.S.,	*Manchester.*
1864	George Gabriel Stokes, M.A., LL.D., D.C.L., Pres. R.S., Corresp. Mem. Inst. France,	*Cambridge.*
1874	James Joseph Sylvester, M.A., LL.D., F.R.S., Corresp. Mem. Inst. France,	*Oxford.*
1864	The Right Hon. Lord Tennyson, D.C.L., LL.D., F.R.S., Poet Laureate,	*Isle of Wight.*
1883	Alexander William Williamson, LL.D., F.R.S., V.P.C.S., Corresp. Mem. Inst. France,	*London.*
1883	Colonel Henry Yule, C.B., LL.D., Member of the Council of India,	*London.*

Total, 20.

ORDINARY FELLOWS ELECTED

During Session 1883–84,

Arranged according to the Date of their Election.

7th January 1884.

Francis T. Bond, M.D., B.A.

4th February 1884.

George M. Low, Actuary.
Dr Frederick Hungerford Bowman, F.R.A.S.
Rev. J. Gordon Macpherson, M.A., D.Sc.
Charles Scott Dickson, Advocate.
Robert Traill Omond.

3rd March 1884.

G. A. Woods, M.R.C.S.
Richard Davy, M.D.
John Grieve, M.A., M.D.

7th April 1884.

James Tait Black.
E. Peirson Ramsay, F.L.S.

5th May 1884.

Professor Joseph Shield Nicholson.
Rev. J. S. Black.
John Henderson, Jun.

2nd June 1884.

J. T. Cunningham, B.A.

7th July 1884.

David Alan Stevenson, B.Sc., C.E.
R. W. Mylne, C.E., F.R.S.
W. Evans, F.F.A.
George Hunter MacThomas Thoms, of Aberlemno, Sheriff of Caithness, Orkney, and Zetland.

FELLOWS DECEASED, RESIGNED, OR CANCELLED,

During Session 1883–84.

DECEASED.

Professor John Hutton Balfour.
The Duke of Buccleuch.
Isaac Anderson Henry.
Ex-Provost Lindsay of Leith.
C. H. Millar of Blaircastle.
Joseph Mitchell.
Dr Allan Thomson.
Dr Alexander Wood.

RESIGNED.

Alexander Howe, W.S.

CANCELLED.

Francis W. Moinet, M.D.

ELECTION OF HONORARY FELLOWS.

FOREIGN HONORARY FELLOWS.

16th June 1884.

M. Charles Hermite, *Paris.*
M. Pierre J. van Beneden, *Louvain.*

BRITISH HONORARY FELLOWS.

7th July 1884.

Professor E. Frankland, D.C.L., LL.D., F.R.S.
William Huggins, D.C.L., LL.D., F.R.S.
Professor Burdon Sanderson, M.D., LL.D., F.R.S.

FOREIGN HONORARY FELLOWS DECEASED.

Session 1883–84.

Jean Baptiste Dumas.
Richard Lepsius.
Charles Adolphe Wurtz.

ORDINARY FELLOWS ELECTED

During Session 1884–85,

Arranged according to the Date of their Election.

1st December 1884.

H. Bellyse Baildon, B.A. — Robert Chambers.
Charles M'Bride, M.D.

2nd February 1885.

Professor W. R. Hodgkinson. — John Rattray, M.A., B.Sc.
Hugh Robert Mill, B.Sc. — William Miller, S.S.C.
Alfred Daniell, M.A., LL.B., D.Sc.

2nd March 1885.

Professor Elgar. — Orme Masson, D.Sc.
J. M. Macfarlane, D.Sc.

6th April 1885.

Professor J. E. A. Steggall. — R. J. Harvey Gibson, M.A.
James Pringle, Provost of Leith. — Professor Dyce Davidson, M.D.
A. P. Laurie, B.Sc. — George Smith, F.C.S.

4th May 1885.

Johnson Symington, M.B., F.R.C.S.E. — Professor J. M. Dixon.
J. F. Pullar. — J. Macdonald Brown, M.B., F.R.C.S.

1st June 1885.

Professor D'Arcy W. Thompson. — A. Y. Fraser, M.A.
Alexander Scott, M.A., D.Sc.

FELLOWS DECEASED OR RESIGNED

During Session 1884–85.

DECEASED.

Sir James Alexander, K.C.B.
W. Lindsay Alexander, D.D.
T. C. Archer, Museum of Science and Art.
Augustus J. D. Cameron, M. Inst. C.E.
Francis Brown Douglas, Advocate.
Frederick Field, F.R.S.
Principal Sir Alexander Grant, Bart.
Professor H. C. Fleeming Jenkin, F.R.S.
J. W. Laidlay of Seacliffe.
John Macnair.
James Napier of Partick.
Rev. Francis Redford, M.A.
Major-General A. Cunningham Robertson.
Professor Morrison Watson, M.D.
Walter Weldon, F.R.S.
Thomas Wright, M.D.

RESIGNED.

R. K. Galloway, Esq., B.A.
John Dick Peddie, Esq.

FOREIGN HONORARY FELLOWS DECEASED.

Session 1884–85.

Henry Milne-Edwards.
Karl Theodor von Siebold.

ORDINARY FELLOWS ELECTED

During Session 1885–86,

Arranged according to the Date of their Election.

7th December 1885.

Dr A. B. Griffiths, F.C.S., School of Science of the City and County of Leicester.

David Cunningham, M. Inst. C.E.

Daniel M. Connan, M.A., Education Department, Cape Town.

4th January 1886.

A. J. G. Barclay, M.A.

1st February 1886.

The Right Hon. J. H. A. Macdonald.

Professor Frederick O. Bower.

Robert Irvine.

German Sims Woodhead, M.D.

Arthur W. Hare, M.B., C.M.

George Fosbery Lyster, M. Inst. C.E.

D. Noel Paton, M.D., B.Sc.

Rev. George Laing.

William J. Macdonald, M.A.

1st March 1886.

Hugh Miller, H.M. Geological Survey.

John Richard Brittle, M. Inst. C.E.

The Right Hon. Sir Thomas Clark, Bart., Lord Provost.

Professor Robert Wallace.

Professor George Frederick Armstrong, M.A., F.G.S.

Arthur Anderson, C.B., M.D.

Alexander Gibson, Advocate.

Colonel R. Murdoch Smith.

The Right Hon. the Earl of Haddington.

5th April 1886.

A. Beatson Bell, Chairman of Prison Commissioners.

J. P. B. Robertson, Q.C., M.P.

John Halliday Croom, M.D.

D. Bruce Peebles.

C. Leopold Field, F.C.S.

Rev. J. MacGregor, D.D.

3rd May 1886.

Charles Frederick Pollock, M.D., F.R.C.S.E.

Professor Greenfield.

Byrom Bramwell, M.D.

C. A. Stevenson, B.Sc., F.R.C.P.E.

William Milne, M.A., B.Sc.

7th June 1886.

James Oliver, M.B., M.R.C.P. Lond.

5th July 1886.

Robert Kidston, F.G.S.

Rev. H. G. Bonavia Hunt, Mus. B. Oxon., F.R.A.S., F.L.S.

FELLOWS DECEASED OR RESIGNED

During Session 1885–86.

DECEASED.

Sir John Anderson, LL.D.
The Right Rev. Bishop Cotterill, D.D., LL.D.
James T. Gibson-Craig, W.S.
Professor A. Dyce Davidson, M.A., M.D.
James Dunsmure, M.D., F.R.C.S.E.
W. Mitchell Ellis, Advocate.
J. Sampson Gamgee.
Frederick Guthrie, M.A., F.R.S.
* Alexander Hamilton, LL.B., W.S.
Cosmo Gordon Logie, M.D.
Angus Macdonald, M.D., F.R.C.P.E.
Graeme Reid Mercer of Gorthie.
John Milne.
John Milroy of Torsonce.
David Stevenson, M. Inst. C.E.
William Turnbull.
Thomas Williamson, M.D., F.R.C.S.E.

* Died 1st January 1884. Death only intimated on 17th June 1886.

RESIGNED.

George F. Barbour of Bonskeid.

BRITISH HONORARY FELLOW DECEASED.

Session 1885–86.

Thomas Andrews, M.D., LL.D., F.R.S.

LAWS

OF THE

ROYAL SOCIETY OF EDINBURGH,

AS REVISED 20TH FEBRUARY 1882.

LAWS.

[By the Charter of the Society (printed in the *Transactions*, Vol. VI. p. 5), the Laws cannot be altered, except at a Meeting held one month after that at which the Motion for alteration shall have been proposed.]

I.

THE ROYAL SOCIETY OF EDINBURGH shall consist of Ordinary and Honorary Fellows. Title.

II.

Every Ordinary Fellow, within three months after his election, shall pay Two Guineas as the fee of admission, and Three Guineas as his contribution for the Session in which he has been elected; and annually at the commencement of every Session, Three Guineas into the hands of the Treasurer. This annual contribution shall continue for ten years after his admission, and it shall be limited to Two Guineas for fifteen years thereafter.* The fees of Ordinary Fellows residing in Scotland.

III.

All Fellows who shall have paid Twenty-five years' annual contribution shall be exempted from farther payment. Payment to cease after 25 years.

IV.

The fees of admission of an Ordinary Non-Resident Fellow shall be £26, 5s., payable on his admission; and in case of any Non-Resident Fellow coming to reside at any time in Scotland, he shall, during each year of his residence, pay the usual annual contribution of £3, 3s., payable by each Resident Fellow; but after payment of such annual contribution for eight years, he shall be exempt Fees of Non-Resident Ordinary Fellows.

* A modification of this rule, in certain cases, was agreed to at a Meeting of the Society held on the 3rd January 1831.

At the Meeting of the Society, on the 5th January 1857, when the reduction of the Contributions from £3, 3s. to £2, 2s., from the 11th to the 25th year of membership, was adopted, it was resolved that the existing Members shall share in this reduction, so far as regards their future annual Contributions.

Case of Fellows becoming Non-Resident.

from any farther payment. In the case of any Resident Fellow ceasing to reside in Scotland, and wishing to continue a Fellow of the Society, it shall be in the power of the Council to determine on what terms, in the circumstances of each case, the privilege of remaining a Fellow of the Society shall be continued to such Fellow while out of Scotland.

V.

Defaulters.

Members failing to pay their contributions for three successive years (due application having been made to them by the Treasurer) shall be reported to the Council, and, if they see fit, shall be declared from that period to be no longer Fellows, and the legal means for recovering such arrears shall be employed.

VI.

Privileges of Ordinary Fellows.

None but Ordinary Fellows shall bear any office in the Society, or vote in the choice of Fellows or Office-Bearers, or interfere in the patrimonial interests of the Society.

VII.

Numbers Unlimited.

The number of Ordinary Fellows shall be unlimited.

VIII.

Fellows entitled to Transactions.

The Ordinary Fellows, upon producing an order from the TREASURER, shall be entitled to receive from the Publisher, gratis, the Parts of the Society's Transactions which shall be published subsequent to their admission.

IX.

Mode of Recommending Ordinary Fellows.

Candidates for admission as Ordinary Fellows shall make an application in writing, and shall produce along with it a certificate of recommendation to the purport below,* signed by at least *four* Ordinary Fellows, two of whom shall certify their recommendation from personal knowledge. This recommendation shall be delivered to the Secretary, and by him laid before the Council, and shall afterwards be printed in the circulars for three Ordinary Meetings of the Society, previous to the day of election, and shall lie upon the table during that time.

* "A. B., a gentleman well versed in Science (*or Polite Literature, as the case may be*), being "to our knowledge desirous of becoming a Fellow of the Royal Society of Edinburgh, we hereby "recommend him as deserving of that honour, and as likely to prove a useful and valuable Member.

X.

Honorary Fellows shall not be subject to any contribution. This class shall consist of persons eminently distinguished for science or literature. Its number shall not exceed Fifty-six, of whom Twenty may be British subjects, and Thirty-six may be subjects of foreign states. Honorary Fellows, British and Foreign.

XI.

Personages of Royal Blood may be elected Honorary Fellows, without regard to the limitation of numbers specified in Law X. Royal Personages.

XII.

Honorary Fellows may be proposed by the Council, or by a recommendation (in the form given below*) subscribed by three Ordinary Fellows; and in case the Council shall decline to bring this recommendation before the Society, it shall be competent for the proposers to bring the same before a General Meeting. The election shall be by ballot, after the proposal has been communicated *viva voce* from the Chair at one meeting, and printed in the circulars for two ordinary meetings of the Society, previous to the day of election. Recommendation of Honorary Fellows. Mode of Election.

XIII.

The election of Ordinary Fellows shall only take place at the first Ordinary Meeting of each month during the Session. The election shall be by ballot, and shall be determined by a majority of at least two-thirds of the votes, provided Twenty-four Fellows be present and vote. Election of Ordinary Fellows.

XIV.

The Ordinary Meetings shall be held on the first and third Mondays of every month from December to July inclusively; excepting when there are five Mondays in January, in which case the Meetings for that month shall be held on its third and fifth Mondays. Regular Minutes shall be kept of the proceedings, and the Secretaries shall do the duty alternately, or according to such agreement as they may find it convenient to make. Ordinary Meetings.

* We hereby recommend_____
for the distinction of being made an Honorary Fellow of this Society, declaring that each of us from our own knowledge of his services to (*Literature or Science, as the case may be*) believe him to be worthy of that honour.

(To be signed by three Ordinary Fellows.)

_____

_____

_____

To the President and Council of the Royal Society of Edinburgh.

XV.

The Transactions.

The Society shall from time to time publish its Transactions and Proceedings. For this purpose the Council shall select and arrange the papers which they shall deem it expedient to publish in the *Transactions* of the Society, and shall superintend the printing of the same.

The Council shall have power to regulate the private business of the Society. At any Meeting of the Council the Chairman shall have a casting as well as a deliberative vote.

XVI.

How Published.

The Transactions shall be published in parts or *Fasciculi* at the close of each Session, and the expense shall be defrayed by the Society.

XVII.

The Council.

That there shall be formed a Council, consisting—First, of such gentlemen as may have filled the office of President; and Secondly, of the following to be annually elected, viz. :—a President, Six Vice-Presidents (two at least of whom shall be resident), Twelve Ordinary Fellows as Councillors, a General Secretary, Two Secretaries to the Ordinary Meetings, a Treasurer, and a Curator of the Museum and Library.

XVIII.

Retiring Councillors.

Four Councillors shall go out annually, to be taken according to the order in which they stand on the list of the Council.

XIX.

Election of Office-Bearers.

An Extraordinary Meeting for the Election of Office-Bearers shall be held on the fourth Monday of November annually.

XX.

Special Meetings; how called.

Special Meetings of the Society may be called by the Secretary, by direction of the Council; or on a requisition signed by six or more Ordinary Fellows. Notice of not less than two days must be given of such Meetings.

XXI.

Treasurer's Duties.

The Treasurer shall receive and disburse the money belonging to the Society, granting the necessary receipts, and collecting the money when due.

He shall keep regular accounts of all the cash received and expended, which shall be made up and balanced annually; and at the Extraordinary Meeting in November, he shall present the accounts for the preceding year, duly audited.

At this Meeting, the Treasurer shall also lay before the Council a list of all arrears due above two years, and the Council shall thereupon give such directions as they may deem necessary for recovery thereof.

XXII.

Auditor.

At the Extraordinary Meeting in November, a professional accountant shall be chosen to audit the Treasurer's accounts for that year, and to give the necessary discharge of his intromissions.

XXIII.

General Secretary's Duties.

The General Secretary shall keep Minutes of the Extraordinary Meetings of the Society, and of the Meetings of the Council, in two distinct books. He shall, under the direction of the Council, conduct the correspondence of the Society, and superintend its publications. For these purposes he shall, when necessary, employ a clerk, to be paid by the Society.

XXIV.

Secretaries to Ordinary Meetings.

The Secretaries to the Ordinary Meetings shall keep a regular Minute-book, in which a full account of the proceedings of these Meetings shall be entered; they shall specify all the Donations received, and furnish a list of them, and of the Donors' names, to the Curator of the Library and Museum; they shall likewise furnish the Treasurer with notes of all admissions of Ordinary Fellows. They shall assist the General Secretary in superintending the publications, and in his absence shall take his duty.

XXV.

Curator of Museum and Library.

The Curator of the Museum and Library shall have the custody and charge of all the Books, Manuscripts, objects of Natural History, Scientific Productions, and other articles of a similar description belonging to the Society; he shall take an account of these when received, and keep a regular catalogue of the whole, which shall lie in the Hall, for the inspection of the Fellows.

XXVI.

Use of Museum and Library.

All Articles of the above description shall be open to the inspection of the Fellows at the Hall of the Society, at such times and under such regulations, as the Council from time to time shall appoint.

XXVII.

Register Book.

A Register shall be kept, in which the names of the Fellows shall be enrolled at their admission, with the date.

THE KEITH, BRISBANE, AND NEILL PRIZES.

The above Prizes will be awarded by the Council in the following manner :—

I. KEITH PRIZE.

The KEITH PRIZE, consisting of a Gold Medal and from £40 to £50 in Money, will be awarded in the Session 1887–88 for the "best communication on a scientific subject, communicated, in the first instance, to the Royal Society during the Sessions 1885–86 and 1886–87." Preference will be given to a paper containing a discovery.

II. MAKDOUGALL-BRISBANE PRIZE.

This Prize is to be awarded biennially by the Council of the Royal Society of Edinburgh to such person, for such purposes, for such objects, and in such manner as shall appear to them the most conducive to the promotion of the interests of science; with the *proviso* that the Council shall not be compelled to award the Prize unless there shall be some individual engaged in scientific pursuit, or some paper written on a scientific subject, or some discovery in science made during the biennial period, of sufficient merit or importance in the opinion of the Council to be entitled to the Prize.

1. The Prize, consisting of a Gold Medal and a sum of Money, will be awarded at the commencement of the Session 1887–88, for an Essay or Paper having reference to any branch of scientific inquiry, whether Material or Mental.

2. Competing Essays to be addressed to the Secretary of the Society, and transmitted not later than 1st June 1888.

3. The Competition is open to all men of science.

4. The Essays may be either anonymous or otherwise. In the former case, they must be distinguished by mottoes, with corresponding sealed billets, superscribed with the same motto, and containing the name of the Author.

5. The Council impose no restriction as to the length of the Essays, which may be, at the discretion of the Council, read at the Ordinary Meetings of the Society. They wish also to leave the property and free disposal of the manuscripts to the Authors; a copy, however, being deposited in the Archives of the Society, unless the paper shall be published in the Transactions.

6. In awarding the Prize, the Council will also take into consideration any scientific papers presented to the Society during the Sessions 1887–88 and 1883–84, whether they may have been given in with a view to the prize or not.

III. NEILL PRIZE.

The Council of the Royal Society of Edinburgh having received the bequest of the late Dr PATRICK NEILL of the sum of £500, for the purpose of "the interest thereof being applied in furnishing a Medal or other reward every second or third year to any distinguished Scottish Naturalist, according as such Medal or reward shall be voted by the Council of the said Society," hereby intimate,

1. The NEILL PRIZE, consisting of a Gold Medal and a sum of Money, will be awarded during the Session 1888–89.

2. The Prize will be given for a Paper of distinguished merit, on a subject of Natural History, by a Scottish Naturalist, which shall have been presented to the Society during the three years preceding the 1st May 1888,—or failing presentation of a paper sufficiently meritorious, it will be awarded for a work or publication by some distinguished Scottish Naturalist, on some branch of Natural History, bearing date within five years of the time of award.

AWARDS OF THE KEITH, MAKDOUGALL-BRISBANE, AND NEILL PRIZES, FROM 1827 TO 1879.

I. KEITH PRIZE.

1st Biennial Period, 1827–29.—Dr Brewster, for his papers "on his Discovery of Two New Immiscible Fluids in the Cavities of certain Minerals," published in the Transactions of the Society.

2nd Biennial Period, 1829–31.—Dr Brewster, for his paper "on a New Analysis of Solar Light," published in the Transactions of the Society.

3rd Biennial Period, 1831–33.—Thomas Graham, Esq., for his paper "on the Law of the Diffusion of Gases," published in the Transactions of the Society.

4th Biennial Period, 1833–35.—Professor J. D. Forbes, for his paper "on the Refraction and Polarization of Heat," published in the Transactions of the Society.

5th Biennial Period, 1835–37.—John Scott Russell, Esq., for his Researches "on Hydrodynamics," published in the Transactions of the Society.

6th Biennial Period, 1837–39.—Mr John Shaw, for his experiments "on the Development and Growth of the Salmon," published in the Transactions of the Society.

7th Biennial Period, 1839–41.—Not awarded.

8th Biennial Period, 1841–43.—Professor James David Forbes, for his Papers "on Glaciers," published in the Proceedings of the Society.

9th Biennial Period, 1843–45.—Not awarded.

10th Biennial Period, 1845–47.—General Sir Thomas Brisbane, Bart., for the Makerstoun Observations on Magnetic Phenomena, made at his expense, and published in the Transactions of the Society.

11th Biennial Period, 1847–49.—Not awarded.

12th Biennial Period, 1849–51.—Professor Kelland, for his papers "on General Differentiation, including his more recent communication on a process of the Differential Calculus, and its application to the solution of certain Differential Equations," published in the Transactions of the Society.

13th Biennial Period, 1851–53.—W. J. Macquorn Rankine, Esq., for his series of papers "on the Mechanical Action of Heat," published in the Transactions of the Society.

14th Biennial Period, 1853–55.—Dr Thomas Anderson, for his papers "on the Crystalline Constituents of Opium, and on the Products of the Destructive Distillation of Animal Substances," published in the Transactions of the Society.

15th Biennial Period, 1855–57.—Professor Boole, for his Memoir "on the Application of the Theory of Probabilities to Questions of the Combination of Testimonies and Judgments," published in the Transactions of the Society.

16th Biennial Period, 1857–59.—Not awarded.

17th Biennial Period, 1859–61.—John Allan Broun, Esq., F.R.S., Director of the Trevandrum Observatory, for his papers "on the Horizontal Force of the Earth's Magnetism, on the Correction of the Bifilar Magnetometer, and on Terrestrial Magnetism generally," published in the Transactions of the Society.

18th Biennial Period, 1861–63.—Professor William Thomson, of the University of Glasgow, for his Communication "on some Kinematical and Dynamical Theorems."

19th Biennial Period, 1863–65.—Principal Forbes, St Andrews, for his "Experimental Inquiry into the Laws of Conduction of Heat in Iron Bars," published in the Transactions of the Society,

20TH BIENNIAL PERIOD, 1865–67.—Professor C. PIAZZI SMYTH, for his paper "on Recent Measures at the Great Pyramid," published in the Transactions of the Society.

21ST BIENNIAL PERIOD, 1867–69.—Professor P. G. TAIT, for his paper "on the Rotation of a Rigid Body about a Fixed Point," published in the Transactions of the Society.

22ND BIENNIAL PERIOD, 1869–71.—Professor CLERK MAXWELL, for his paper "on Figures, Frames, and Diagrams of Forces," published in the Transactions of the Society.

23RD BIENNIAL PERIOD, 1871–73.—Professor P. G. TAIT for his paper entitled "First Approximation to a Thermo-electric Diagram," published in the Transactions of the Society.

24TH BIENNIAL PERIOD, 1873–75.—Professor CRUM BROWN, for his Researches "on the sense of Rotation, and on the Anatomical Relations of the Semicircular Canals of the Internal Ear."

25TH BIENNIAL PERIOD, 1875–77.—Professor M. FORSTER HEDDLE, for his papers "on the Rhombohedral Carbonates," and "on the Felspars of Scotland," published in the Transactions of the Society.

26TH BIENNIAL PERIOD, 1877–79.—Professor H. C. FLEEMING JENKIN, for his paper "on the Application of Graphic Methods to the Determination of the Efficiency of Machinery," published in the Transactions of the Society; Part II. having appeared in the volume for 1877–78.

27TH BIENNIAL PERIOD, 1879–81.—Professor GEORGE CHRYSTAL, for his paper "on the Differential Telephone," published in the Transactions of the Society.

28TH BIENNIAL PERIOD, 1881–83.—THOMAS MUIR, Esq., LL.D., for his "Researches into the Theory of Determinants and Continued Fractions," published in the Proceedings of the Society.

29TH BIENNIAL PERIOD, 1883–85.—JOHN AITKEN, Esq., for his paper "on the Formation of Small Clear Spaces in Dusty Air," and for previous papers on Atmospheric Phenomena, published in the Transactions of the Society.

II. MAKDOUGALL-BRISBANE PRIZE.

1ST BIENNIAL PERIOD, 1859.—Sir RODERICK IMPEY MURCHISON, on account of his Contributions to the Geology of Scotland.

2ND BIENNIAL PERIOD, 1860–62.—WILLIAM SELLER, M.D., F.R.C.P.E., for his "Memoir of the Life and Writings of Dr Robert Whytt," published in the Transactions of the Society.

3RD BIENNIAL PERIOD, 1862–64.—JOHN DENIS MACDONALD, Esq., R.N., F.R.S., Surgeon of H.M.S. "Icarus," for his paper "on the Representative Relationships of the Fixed and Free Tunicata, regarded as Two Sub-classes of equivalent value; with some General Remarks on their Morphology," published in the Transactions of the Society.

4TH BIENNIAL PERIOD, 1864–66.—Not awarded.

5TH BIENNIAL PERIOD, 1866–68.—Dr ALEXANDER CRUM BROWN and Dr THOMAS RICHARD FRASER, for their conjoint paper "on the Connection between Chemical Constitution and Physiological Action," published in the Transactions of the Society.

6TH BIENNIAL PERIOD, 1868–70.—Not awarded.

7TH BIENNIAL PERIOD, 1870–72.—GEORGE JAMES ALLMAN, M.D., F.R.S., Emeritus Professor of Natural History, for his paper "on the Homological Relations of the Cœlenterata," published in the Transactions, which forms a leading chapter of his Monograph of Gymnoblastic or Tubularian Hydroids—since published.

8TH BIENNIAL PERIOD, 1872–74.—Professor LISTER, for his paper "on the Germ Theory of Putrefaction and the Fermentive Changes," communicated to the Society, 7th April 1873.

9TH BIENNIAL PERIOD, 1874–76.—ALEXANDER BUCHAN, A.M., for his paper "on the Diurnal Oscillation of the Barometer," published in the Transactions of the Society.

10TH BIENNIAL PERIOD, 1876–78.—Professor ARCHIBALD GEIKIE, for his paper "on the Old Red Sandstone of Western Europe," published in the Transactions of the Society.

11TH BIENNIAL PERIOD, 1878–80.—Professor PIAZZI SMYTH, Astronomer-Royal for Scotland, for his paper "on the Solar Spectrum in 1877–78, with some Practical Idea of its probable Temperature of Origination," published in the Transactions of the Society.

12TH BIENNIAL PERIOD, 1880–82.—Professor JAMES GEIKIE, for his "Contributions to the Geology of the North-West of Europe," including his paper "on the Geology of the Faröes," published in the Transactions of the Society.

13TH BIENNIAL PERIOD, 1882–84.—EDWARD SANG, Esq., LL.D., for his paper "on the Need of Decimal Subdivisions in Astronomy and Navigation, and on Tables requisite therefor," and generally for his Recalculation of Logarithms both of Numbers and Trigonometrical Ratios, —the former communication being published in the Proceedings of the Society.

III. THE NEILL PRIZE.

1ST TRIENNIAL PERIOD, 1856–59.—Dr W. LAUDER LINDSAY, for his paper "on the Spermogones and Pycnides of Filamentous, Fruticulose, and Foliaceous Lichens," published in the Transactions of the Society.

2ND TRIENNIAL PERIOD, 1859–62.—ROBERT KAYE GREVILLE, LL.D., for his Contributions to Scottish Natural History, more especially in the department of Cryptogamic Botany, including his recent papers on Diatomaceæ.

3RD TRIENNIAL PERIOD, 1862–65.—ANDREW CROMBIE RAMSAY, F.R.S., Professor of Geology in the Government School of Mines, and Local Director of the Geological Survey of Great Britain, for his various works and Memoirs published during the last five years, in which he has applied the large experience acquired by him in the Direction of the arduous work of the Geographical Survey of Great Britain to the elucidation of important questions bearing on Geological Science.

4TH TRIENNIAL PERIOD, 1865–68.—Dr WILLIAM CARMICHAEL M'INTOSH, for his paper "on the Structure of the British Nemerteans, and on some New British Annelids," published in the Transactions of the Society.

5TH TRIENNIAL PERIOD, 1868–71.—Professor WILLIAM TURNER, for his papers "on the great Finner Whale; and on the Gravid Uterus, and the Arrangement of the Fœtal Membranes in the Cetacea," published in the Transactions of the Society.

6TH TRIENNIAL PERIOD, 1871–74.—CHARLES WILLIAM PEACH, for his Contributions to Scottish Zoology and Geology, and for his recent contributions to Fossil Botany.

7TH TRIENNIAL PERIOD, 1874–77.—Dr RAMSAY H. TRAQUAIR, for his paper "on the Structure and Affinities of *Tristichopterus alatus* (Egerton)," published in the Transactions of the Society, and also for his contributions to the Knowledge of the Structure of Recent and Fossil Fishes.

8TH TRIENNIAL PERIOD, 1877–80.—JOHN MURRAY, for his paper "on the Structure and Origin of Coral Reefs and Islands," published (in abstract) in the Proceedings of the Society.

9TH TRIENNIAL PERIOD, 1880–83.—Professor HERDMAN, for his papers "on the Tunicata," published in the Proceedings and Transactions of the Society.

10TH TRIENNIAL PERIOD, 1883–86.—B. N. PEACH, Esq., for his Contributions to the Geology and Palæontology of Scotland, published in the Transactions of the Society.

PROCEEDINGS

OF THE

STATUTORY GENERAL MEETINGS,

AND

LIST OF MEMBERS ELECTED AT THE ORDINARY MEETINGS

FROM NOVEMBER 1881 TO NOVEMBER 1885.

STATUTORY MEETINGS.

NINETY-NINTH SESSION.

Monday, 28th November 1881.

At a Statutory Meeting, Professor MACLAGAN, Vice-President, in the Chair, the Minutes of last General Statutory Meeting of 22nd November 1880 were read, approved, and signed.

The Ballot for the new Council was then taken, Messrs TENNANT and MACCULLOCH being requested to act as Scrutineers. The following Council was elected:—

The Right Hon. LORD MONCREIFF, President.
DAVID MILNE HOME, LL.D.
Sir C. WYVILLE THOMSON, LL.D.
Professor DOUGLAS MACLAGAN, M.D.
Professor H. C. FLEEMING JENKIN, F.R.S.
Rev. W. LINDSAY ALEXANDER, D.D.
J. H. BALFOUR, M.D., F.R.S.
} Vice-Presidents.
Professor TAIT, General Secretary.
Professor TURNER, F.R.S.
Professor CRUM BROWN, F.R.S.
} Secretaries to Ordinary Meetings.
ADAM GILLIES SMITH, C.A., Treasurer.
ALEXANDER BUCHAN, M.A., Curator of Library and Museum.

COUNCILLORS.

Professor CAMPBELL FRASER.
Professor GEIKIE, F.R.S.
Rev. Dr CAZENOVE.
DAVID STEVENSON.
Professor CHRYSTAL.
Sheriff FORBES IRVINE, of Drum.
Professor A. DICKSON.
The Right Rev. BISHOP COTTERILL.
The Rev. Professor DUNS.
Dr RAMSAY TRAQUAIR, F.R.S.
JOHN MURRAY.
WILLIAM FERGUSON, of Kinmundy.

The TREASURER's Accounts were submitted and approved.

On the motion of Professor TAIT, seconded by Mr MACCULLOCH, the Auditor was re-appointed.

Professor CRUM BROWN gave notice of the following motion for alteration of a part of the Laws, viz., To change in Law XIV. the words "*November to June*" into "*December to July.*"

HUNDREDTH SESSION.

Monday, 27th November 1882.

At a Statutory Meeting, Professor MACLAGAN, Vice-President, in the Chair, the Minutes of last General Statutory Meeting of 28th November 1881 were read, approved, and signed.

The Ballot for the new Council was then taken, Professor SWAN and Professor DICKSON being requested to act as Scrutineers. The following Council was elected:—

The Right Hon. LORD MONCREIFF, President.
Professor DOUGLAS MACLAGAN, M.D.
Professor H. C. FLEEMING JENKIN, F.R.S.
The Rev. W. LINDSAY ALEXANDER, D.D.
J. H. BALFOUR, M.D.
THOMAS STEVENSON, M.Inst. C.E.
ROBERT GRAY, Sec. Roy. Phys. Soc.
} Vice-Presidents.
Professor TAIT, M.A., General Secretary.
Professor TURNER, F.R.S.
Professor CRUM BROWN, F.R.S.,
} Secretaries to Ordinary Meetings.
ADAM GILLIES SMITH, C.A., Treasurer.
ALEXANDER BUCHAN, M.A., Curator of Library and Museum.

COUNCILLORS.

Professor GEORGE CHRYSTAL, M.A.
ALEXANDER FORBES IRVINE, of Drum.
Professor ALEXANDER DICKSON, M.D.
The Right Rev. BISHOP COTTERILL, D.D.
The Rev. Professor DUNS.
RAMSAY H. TRAQUAIR, M.D., F.R.S.
JOHN MURRAY, Director of "Challenger" Commission.
WILLIAM FERGUSON, of Kinmundy.
Professor JAMES COSSAR EWART, M.D.
Professor JAMES GEIKIE, F.R.S.
Professor WILLIAM ROBERTSON SMITH, LL.D.
STAIR A. AGNEW, M.A.

Read Letter from the Treasurer apologising for absence on account of illness, and explaining the apparent surplus shown by the Financial Statement.

The Auditor's Report on the Treasurer's Accounts was read and approved.

On the motion of Dr CRUM BROWN, the Auditor was reappointed.

HUNDRED AND FIRST SESSION.

Monday, 26th November 1883.

At a General Statutory Meeting, THOMAS STEVENSON, Esq., Vice-President, in the Chair, the Minutes of last General Statutory Meeting of 27th November 1882 were read, approved, and signed.

The Ballot for the new Council was then taken, Professors SWAN and DUNS being requested to act as Scrutineers. The following Council was unanimously elected:—

The Right Hon. LORD MONCREIFF, President.
Professor H. C. FLEEMING JENKIN, F.R.S.
The Rev. W. LINDSAY ALEXANDER, D.D.
THOMAS STEVENSON, Esq., M.Inst. C.E.
ROBERT GRAY, Esq., Sec. Roy. Phys. Soc.
A. FORBES IRVINE, Esq. of Drum.
EDWARD SANG, LL.D.
} Vice-Presidents.
Professor TAIT, M.A., General Secretary.
Professor TURNER, F.R.S.
Professor CRUM BROWN, F.R.S.
} Secretaries to Ordinary Meetings.
ADAM GILLIES SMITH, Esq., C.A., Treasurer.
ALEXANDER BUCHAN, Esq., M.A., Curator of Library and Museum.

COUNCILLORS.

The Rev. Professor DUNS.
Dr RAMSAY TRAQUAIR.
JOHN MURRAY, Esq., Director of "Challenger" Commission.
WILLIAM FERGUSON, Esq. of Kinmundy.
Professor COSSAR EWART, M.D.
Professor JAMES GEIKIE, F.R.S.
The Rev. Dr W. ROBERTSON SMITH.
STAIR AGNEW, Esq.
Professor DOUGLAS MACLAGAN, M.D.
The Hon. LORD MACLAREN.
The Rev. Professor FLINT, D.D.
Professor T. R. FRASER, M.D.

The Treasurer's Accounts, duly vouched, were laid on the Table.

The Auditor's Report was read and approved.

On the motion of Professor CRUM BROWN, the Auditor was reappointed.

The General Secretary presented an Agreement by the Scottish Meteorological Society, binding that body to relieve the Royal Society from all pecuniary and other claims connected with the Observatory Site on Ben Nevis. It was moved by Mr FERGUSON, seconded by Sheriff IRVINE, and carried unanimously, That the Secretary be empowered to sign the Agreement on behalf of the Society.

On the motion of Mr YOUNG, a vote of thanks was passed to the Chairman.

HUNDRED AND SECOND SESSION.

Monday, 24th November 1884.

At a General Statutory Meeting, ROBERT GRAY, Esq., Vice-President, in the Chair, the Minutes of last General Statutory Meeting of 26th November 1883 were read, approved, and signed.

The Ballot for the new Council was then taken, Professors SWAN and DUNS having been nominated Scrutineers. The following Council was duly elected:—

THOMAS STEVENSON, Esq., M.Inst. C.E., President.
Rev. W. LINDSAY ALEXANDER, D.D.
ROBERT GRAY, Esq.
A. FORBES IRVINE, Esq. of Drum.
EDWARD SANG, LL.D.
DAVID MILNE HOME, Esq.
JOHN MURRAY, Esq.
} Vice-Presidents.
Professor TAIT, M.A., General Secretary.
Professor TURNER, F.R.S.
Professor CRUM BROWN, F.R.S.
} Secretaries to Ordinary Meetings.
ADAM GILLIES SMITH, Esq., C.A., Treasurer.
ALEXANDER BUCHAN, Esq., M.A., Curator of Library and Museum.

COUNCILLORS.

Professor COSSAR EWART.
Professor JAMES GEIKIE.
Rev. Dr W. ROBERTSON SMITH.
STAIR AGNEW, Esq.
Professor DOUGLAS MACLAGAN, M.D.
The Hon. LORD MACLAREN.
Rev. Professor FLINT, D.D.
Professor T. R. FRASER, M.D.
Professor CHIENE.
J. Y. BUCHANAN, Esq.
Professor CHRYSTAL.
Professor DICKSON.

The Treasurer's Accounts, duly vouched, were laid on the Table.

The Auditor's Report was read, and, on the motion of Sheriff FORBES IRVINE, was unanimously approved.

On the motion of Professor CRUM BROWN, the Auditor was reappointed.

The Secretary and Treasurer were empowered to sign a Discharge by the Society in favour of CHARLES THOMAS BRISBANE, Esq. of Brisbane. Sheriff THOMS was admitted a Fellow.

A vote of thanks was, on the motion of Lord MACLAREN, given to the Chairman.

Monday, 5th October 1885.

At a Special General Meeting called by the Secretary, under Law XX., for the purpose of electing a Member of the New Governing Body of George Heriot's Hospital,—THOMAS STEVENSON, Esq., President, in the Chair,—

The Secretary read Letter from the Lord Provost; also some Excerpts from the Order in Council as to Heriot's Hospital; and explained that the Society's Council had determined that the Election should be conducted in the same manner as that of Office-Bearers.

On the motion of the President, the Rev. Dr GRANT and J. LIVINGSTON, Esq., were requested to act as Scrutineers.

The Scrutineers having examined the Balloting Papers, announced that Dr JOHN MURRAY had been unanimously elected.

HUNDRED AND THIRD SESSION.

Monday, 23rd November 1885.

At a General Statutory Meeting, JOHN MURRAY, Esq., Vice-President, in the Chair, the Minutes of the last General Statutory Meeting, of 24th November 1884, also those of the Special Meeting of 5th October 1885, were read, approved, and signed.

The Chairman requested Professor DUNS and Mr A. YOUNG to act as Scrutineers.

The Ballot for the New Council was then taken, and the Scrutineers reported that the following were unanimously elected:—

THOMAS STEVENSON, Esq., M.Inst. C.E., President.

ROBERT GRAY, Esq.
A. FORBES IRVINE, Esq., of Drum.
DAVID MILNE HOME, Esq.
JOHN MURRAY, Esq.
Professor DOUGLAS MACLAGAN.
The Hon. LORD MACLAREN.
} Vice-Presidents.

Professor TAIT, General Secretary.

Professor TURNER, F.R.S.
Professor CRUM BROWN, F.R.S.
} Secretaries to Ordinary Meetings.

ADAM GILLIES SMITH, Esq., C.A., Treasurer.

ALEXANDER BUCHAN, Esq., M.A., Curator of Library and Museum.

COUNCILLORS.

Rev. Professor FLINT, D.D.
Professor T. R. FRASER, M.D., F.R.S.
Professor CHIENE.
J. Y. BUCHANAN, Esq., M.A.
Professor CHRYSTAL.
Professor DICKSON.
Professor SHIELD NICHOLSON.
T. B. SPRAGUE, Esq.
Professor BUTCHER.
Professor M'KENDRICK, F.R.S.
THOMAS MUIR, Esq., LL.D.
Professor M'INTOSH.

The Secretary laid on the Table the Treasurer's Accounts for the past year, duly vouched. These were approved.

On the motion of Professor CRUM BROWN, seconded by Professor MACLAGAN, the Auditor was re-elected.

The Secretary laid on the Table proofs of the Fasciculi of Proceedings and Transactions shortly to be issued.

A vote of thanks was, on the motion of Professor DUNS, unanimously given to the Chairman.

The following Public Institutions and Individuals are entitled to receive Copies of the Transactions and Proceedings of the Royal Society of Edinburgh:—

London, British Museum.
... Royal Society, Burlington House, London.
... Anthropological Institute of Great Britain and Ireland, 3 Hanover Square, London.
... British Association for the Advancement of Science, 22 Albemarle Street, London.
... Society of Antiquaries, Burlington House.
... Royal Astronomical Society, Burlington House.
... Royal Asiatic Society, 22 Albemarle Street.
... Society of Arts, John Street, Adelphi.
... Athenæum Club.
... Chemical Society, Burlington House.
... Institution of Civil Engineers, 25 Great George Street.
... Royal Geographical Society, Burlington Gardens.
... Geological Society, Burlington House.
... Royal Horticultural Society, South Kensington.
... Hydrographic Office, Admiralty.
... Royal Institution, Albemarle Street, W.
... Linnean Society, Burlington House.
... Royal Society of Literature, 4 St Martin's Place.
... Medical and Chirurgical Society, 53 Berners Street, Oxford Street.
... Royal Microscopical Society, King's College.
... Museum of Economic Geology, Jermyn Street.
... Royal Observatory, Greenwich.
... Pathological Society, 53 Berners Street.
... Statistical Society, 9 Adelphi Terrace, Strand, London.
... Royal College of Surgeons of England, 40 Lincoln's Inn Fields.
London, United Service Institution, Whitehall Yard.
... University College, Gower Street, London.
... Zoological Society, 11 Hanover Square.
... The Editor of *Nature*, 29 Bedford Street, Covent Garden.
... The Editor of the *Electrician*, 396 Strand.
Cambridge Philosophical Society.
... University Library.
Historic Society of Lancashire and Cheshire.
Leeds Philosophical and Literary Society.
Manchester Literary and Philosophical Society.
Oxford, Bodleian Library.
Yorkshire Philosophical Society.

SCOTLAND.

Edinburgh, Advocates Library.
... University Library.
... College of Physicians.
... Highland and Agricultural Society, 3 George IV. Bridge.
... Royal Medical Society, 7 Melbourne Place, Edinburgh.
... Royal Physical Society, 40 Castle Street.
... Royal Scottish Society of Arts, 117 George Street.
... Royal Botanic Garden, Inverleith Row.
Aberdeen, University Library.
Dundee, University College Library.
Glasgow, University Library.
... Philosophical Society, 207 Bath Street.
St Andrews, University Library.

IRELAND.

Royal Dublin Society.
Royal Irish Academy, 19 Dawson Street, Dublin.
Library of Trinity College, Dublin.

COLONIES, DEPENDENCIES, &c.

Bombay, Royal Asiatic Society.
... Elphinstone College.
Calcutta, Asiatic Society of Bengal.
Madras, Literary Society.
Canada, Library of Geological Survey.
... Queen's University, Kingston.
... Montreal, Royal Society of Canada.
... Quebec, Literary and Philosophical Society.
... Toronto, Literary and Historical Society.
... ... The Canadian Institute.
Cape of Good Hope, The Observatory.
Melbourne, University Library.
Sydney, University Library.
... Linnean Society of New South Wales.
... Royal Society of New South Wales.
Wellington, New Zealand Institute.

CONTINENT OF EUROPE.

Amsterdam, Koninklijke Akademie van Wetenschappen
... Koninklijk Zoologisch Genootschap.
Athens, University Library.
Basle, Die Schweizerische Naturforschende Gesellschaft.
Bergen, Museum.
Berlin, Königliche Akademie der Wissenschaften.
... Physicalische Gessellschaft.
Bern, Allgemeine Schweizerische Gesellschaft für die gesammten Naturwissenschaften.
Bologna, Accademia delle Scienze dell' Istituto.
Bordeaux, Société des Sciences Physiques et Naturelles.
Brussels, Académie Royale des Sciences, des Lettres et des Beaux-arts.
... Musée Royal d'Histoire Naturelle de Belgique.
... L'Observatoire Royal.
... La Société Scientifique.
Bucharest, Academia Romana.
Buda, A Magyar Tudós Tarsasag—Die Ungarische Akademie der Wissenschaften.
... Königliche Ungarische Naturwissenschaftlische Gesellschaft.
Catania, Accademia Gioenia di Scienze Naturali.
Christiania, University Library.
... Meteorological Institute.
Coimbra, University Library.
Copenhagen, Royal Academy of Sciences.
Danzig, Naturforschende Gesellschaft.
Dorpat, University Library.
Ekatherinebourg, La Société Ouralienne d'Amateurs des Sciences Naturelles.
Erlangen, University Library.
Frankfurt-am-Main, Senckenbergische Naturforschende Gesellschaft.
Gand (Ghent), University Library.
Geneva, Société de Physique et d' Histoire Naturelle.
Genoa, Museo Civico di Storia Naturale.
Giessen, University Library.
Göttingen, Königliche Gesellschaft der Wissenschaften.
Graz, Naturwissenschaftlicher Verein für Steiermark.
Haarlem, Société Hollandaise des Sciences Exactes et Naturelles.
... Musée Teyler.
Halle, Kaiserliche Leopoldino - Carolinische deutsche Akademie der Naturforscher.
Halle, Naturforschende Gesellschaft.
Hamburg, Naturwissenschaftlicher Verein, 6 Domstrasse.
Helsingfors, Sällskapet pro Fauna et Flora Fennica.
... Societas Scientiarum Fennica (Société des Sciences de Finlande).
Jena, Medicinisch-Naturwissenschaftliche Gesellschaft.
Kasan, University Library.
Kiel, University Library.
... Ministerial-Kommission zur Untersuchung der Deutschen Meere.
Kiev, University of St Vladimir.
Königsberg, University Library.
Leyden, Neerlandsche Dierkundige Vereeniging.
... The University Library.
Leipzig, Prof. Wiedemann, Königliche Sächsische Akademie.
Lille, Société des Sciences.
Lisbon, Academia Real das Sciencias de Lisboa.
... Sociedade de Geographia, 5 Rua Capello.
Louvain, University Library.
Lucca, M. Michelotti.

Lund, University Library.
Lyons, Académie des Sciences, Belles Lettres et Arts.
... Société d'Agriculture.
Madrid, Real Academia de Ciencias.
... Comision del Mapa Geologico de España.
Milan, Reale Istituto Lombardo di Scienze, Lettere, ed Arti.
Modena, Regia Accademia di Scienze, Lettere, ed Arti.
Montpellier, Académie des Sciences et Lettres.
Moscow, Société Impériale des Naturalistes de Moscou.
... Société Impériale des Amis d'Histoire Naturelle, d'Anthropologie et d'Ethnographie.
... Musée Politechnique.
... L'Observatoire Impérial.
Munich, Königlich-Bayerische Akademie der Wissenschaften (2 copies).
Naples, Zoological Station, Dr Anton Dohrn.
... Societa Reale di Napoli—Accademia delle Scienze Fisiche e Matematiche.
Neufchatel, Société des Sciences Naturelles.
Palermo, Signor Agostino Todaro, Giardino Botanico.
... Società di Scienze Naturali ed Economiche.
Paris, Académie des Sciences de l'Institut.
... Académie des Inscriptions et Belles Lettres de l'Institut.
... Association Scientifique de France.
... Société d'Agriculture, 18 Rue de Bellechasse.
... Société Nationale des Antiquaires de France.
... Société de Biologie.
... Société de Géographie, 184 Boulevard St Germain.
... Société Géologique de France, 7 Rue des Grands Augustins.
... Société d'Encouragement pour l'Industrie Nationale.
... Bureau des Longitudes.
... Dépôt de la Marine.
... Société Mathématique, 7 Rue des Grands Augustins.
... École des Mines.
... Ministère de l'Instruction Publique.
Paris, Musée Guimet, 30 Avenue du Trocadero.
... Muséum d' Histoire Naturelle, Jardin des Plantes.
... L'Observatoire.
... École Normale Supérieure, Rue d'Ulm.
... Société Française de Physique, 44 Rue de Rennes.
... École Polytechnique.
... Société Zoologique de France, 7 Rue des Grands Augustins.
... Revue Scientifique, et Revue Littéraire et Politique.
Prague, Königliche Sternwarte.
... Königlich-Böhmische Gesellschaft der Wissenschaften.
Rome, Accademia dei Lincei.
... Società Italiana delle Scienze detta dei XL.
... Società degli Spettroscopisti Italiani.
... Comitato Geologico.
Rotterdam, Bataafsch Genootschap der Proefondervindelijke Wijsbegeerte.
St Petersburg, Académie Impériale des Sciences.
... Commission Impérial Archéologique.
... Comité Géologique.
... L'Observatoire Impérial de Pulkowa.
... Physikalisches Central-Observatorium.
... Physico-Chemical Society of the University of St Petersburg.
Stockholm, Kongliga Svenska Vetenskaps-Academien.
Strasbourg, University Library.
Stuttgart, Verein für Vaterländische Naturkunde zu Würtemberg.
Thronddjem, Videnskabernes Selskab.
Tübingen, University Library.
Turin, Reale Accademia delle Scienze.
Upsala, Kongliga Vetenskaps-Societeten.
Venice, Reale Istituto Veneto di Scienze, Lettere ed Arti.
Vienna, Kaiserliche Akademie der Wissenschaften.
... Novara Commission.
... Oesterreichische Gesellschaft für Meteorologie, Hohe Warte, Wien.
... Geologische Reichsanstalt.
... Zoologisch-Botanische Gesellschaft.

Zurich, University Library.
... Commission Géologique Suisse

ASIA.

Java, Bataviaasch Genootschap van Kunsten en Wetenschappen.
... The Observatory.
Japan, The Imperial University of Tokio (Teikoku-Daigaku).

UNITED STATES OF AMERICA.

American Association for the Advancement of Science.
Baltimore, Johns Hopkins University.
Boston, the Bowditch Library.
... American Academy of Arts and Sciences, Beacon Street, Boston.
... Society of Natural History.
Cambridge, Mass., Harvard University.
... Harvard College Observatory.
Chicago Observatory.
Clinton, Litchfield Observatory, Hamilton College.
Concord, Editor of Journal of Speculative Philosophy.
New York, State Library.
Philadelphia, American Philosophical Society.
... Academy of Natural Sciences, Logan Square.
Philadelphia, Geological Survey of Pennsylvania.
Salem, The Peabody Academy of Science.
St Louis, Academy of Sciences.
Washington, United States Coast Survey.
... United States Fishery Commission.
... United States Naval Observatory.
... United States Geological Survey of the Territories.
... United States Signal Office.
... The Smithsonian Institution.
... Surgeon-General's Office, United States Army.
Wisconsin, University (Washborn Observatory), Madison.
Yale College, Newhaven, Connecticut.

MEXICO.

Mexico, Observatorio Meteorologico Central.

SOUTH AMERICA.

Buenos Ayres, Public Museum, per Dr Burmeister.
Corduba, Argentine Republic, Academia Nacional de Ciencias.
... The Observatory.
Rio de Janeiro, The Astronomical Observatory.

All the Honorary and Ordinary Fellows of the Society are entitled to the Transactions and Proceedings.
See Notice at foot of page 706.

The following Institutions and Individuals receive the Proceedings only :—

SCOTLAND.

Edinburgh, Botanical Society 5 St Andrew Square.
... Geological Society, 5 St Andrew Square.
... Scottish Geographical Society.
... Mathematical Society, 8 Queen Street.
Edinburgh, Scottish Meteorological Society, 122 George Street.
... Pharmaceutical Society, 36 York Place.
Geological Society of Glasgow, 207 Bath Street.
The Glasgow University Observatory.
Berwickshire Naturalists' Club, Old Cambus, Cockburnspath.

ENGLAND.

London, Geologists' Association, University College.
... Mathematical Society, 22 Albemarle Street, London, W.
... Institution of Mechanical Engineers, 10 Victoria Chambers, Victoria Street, Westminster.
... Meteorological Office, 116 Victoria Street.
... The Meteorological Society, 25 Great George Street, Westminster.
... *Nautical Almanac* Office, 3 Verulam Buildings, Gray's Inn.
... Pharmaceutical Society, 17 Bloomsbury Square, London.
... The Editor of the Illustrated Science Monthly, 3 St Martin's Place, Trafalgar Square, London.
Birmingham Philosophical Society, King Edward's Grammar School.
Cornwall, Geological Society.
Epping Forest and County of Essex Naturalists' Field Club.
Halifax, Geological and Polytechnic Society of Yorkshire.
Liverpool, Literary and Philosophical Society.
Manchester, Geological Society, 36 George Street.
Newcastle, Philosophical Society.
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... The Observatory.
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... K. Technische Hochschule.
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Bern, Naturforschende Gesellschaft.
Bordeaux, Société de la Géographie Commerciale.
Brunswick, Verein für Naturwissenschaft.
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Chemnitz, Naturwissenschaftliche Gesellschaft.
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Gratz, Chemisches Institut der K. K. Universität.
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Lausanne, Société Vaudoise des Sciences Naturelles.
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New York, The American Museum of Natural History.
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Salem, The Essex Institute.
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San Francisco, The Lick Observatory.
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